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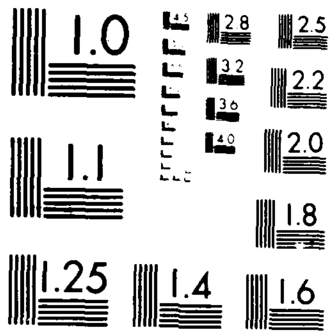
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CALCULATIONS OF NEUTRON AND GAMMA-RAY TRANSPORT IN AIR-OVER-GROUND GEOMETRY
Comparison with BREN and APR Experiments

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1 June 1983

Technical Report

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Calculations of neutron and gamma-ray transport corresponding to the BREN and APR reactor experiments have been performed using the two-dimensional, discrete ordinates transport code DOTSAI. These calculations have been made as a test of state-of-the-art radiation transport techniques and to provide input for further analyses relevant to an ongoing program of Japanese A-bomb survivor dose reassessment. Comparisons of calculated and measured data have produced mixed results. However, it is concluded that modern calculational techniques are capable of accurately reproducing neutron and gamma-ray kerma and spectral distributions to large distances from Co-60 and fast reactor sources in an air-over-ground geometry.

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Discrete Ordinates Transport
Proton Recoil Detector
Geiger-Muller Counter
Air Transport
Integral Experiment

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SECTION 1

INTRODUCTION

As part of an ongoing research effort in connection with the dosimetry reconstruction program for nuclear bomb survivors of Japan, Science Applications, International Company (SAIC) has performed calculations of the radiation fields produced during the BREN-Tower experiments and recent Army Pulse Reactor (APR) measurements. These analyses were performed to test the capabilities of state-of-the-art calculational methods in air-over-ground geometries and to assess the adequacy of basic input parameters used in such computations. In turn, the results were intended to improve levels of understanding for both the analytical and experimental methods. Finally, the BREN calculations were intended to support further studies of structure shielding for the A-bomb survivors in a parallel effort to reproduce the shielding measurements reported by Cheka.[1]

Operation BREN[2] was a support program for the ICHIBAN Study[3], which was established in 1956 to evaluate the radiation doses received by survivors of the nuclear bombing of Hiroshima and Nagasaki in 1945. The ORNL Health Physics Research Reactor (HPRR) was suspended from a 1500 ft. tower in these experiments, and neutron and gamma kerma at various ranges were measured for different reactor heights. Later, an 800-curie Co-60 source was substituted for the reactor and measurements were repeated for pure gamma ray fields.

More recently, a series of experiments have been carried out using the APR reactor on an almost annual basis. During this series of experiments, which began in 1978, differential and integral measurements have been made of the neutron and gamma radiation from the reactor. Three groups of scientists, representing the Army Pulsed Radiation Division of the Material Testing Directorate (APRD Group), Armed Forces Scientific Laboratory for ABC-Defense of the Federal Republic of Germany (WWD Group), and Canadian Defense Research Establishment Ottawa (DREO Group) have taken part in these measurements.

An effort to analytically reproduce the radiation field values measured at BREN and APR was undertaken by SAIC using the two-dimensional discrete ordinates radiation transport code DOTSAI[4] a modified, CDC version of

DOT-III.[5] DOTSAI has been specifically tailored for deep penetration transport problems requiring extremely large amounts of storage on a CYBER-176 system. The Co-60 calculations were repeated using the DOT-IV(4.2)[6] code for comparison purposes.

The balance of this report describes the results of calculations of various quantities corresponding to those measured in the BREN and APR experiments. This description is supported within the text by figures depicting both the calculated and measured data. A tabulation of the calculated data is provided in an appendix to the report.

SECTION 2

BREN TOWER CALCULATIONS

2.1 CO-60 SOURCE

Calculations of Co-60 radiation transport were carried out using the PVC 36-group photon cross section library.[7] Angular scattering dependence was treated using a P_3 Legendre expansion. The boundaries in the DOTSAI calculation were placed at 1500 meters radially and 1000 meters axially, the region within was described using 63 radial and 75 axial meshes, including one meter of ground. Full energy- differential albedoes were employed along the upper and outer boundaries of the geometry. These albedoes were calculated using the results of one dimensional transport calculations in uniform air. The air used in the calculation corresponded to the same air density (1.01 g/l) to which all measured results were normalized.[8] The ground constituents were determined according to recent measurements performed by ORNL.[9] Air and ground constituents for this calculation are shown in Table 1.

The 800 curie Co-60 source was represented by 2.96×10^{13} per second each of 1.17 and 1.33 MeV gamma rays. It was placed at a point 342.9 meters above the ground surface and converted into a volume-distributed source using the analytical first collision source option in DOTSAI. The transport calculation was then performed using a 160 angle (S_{16}) quadrature set. The volume-distributed source and high level quadrature set were chosen to minimize problems of preferential streaming along quadrature angles (ray effects) which plague multi-dimensional discrete ordinates computations of forward-scattering radiation. The degree to which they succeeded in doing so may be judged from the data presented in Figure 1, which are the exposure rate (roentgen/hr) isocontours calculated throughout the atmosphere. Those isocontours appear to be reasonably well behaved, departing from circularity only as caused by the presence of the ground and in a narrow angle band about the source height, which represents the largest step in the angular quadrature.

Calculated and measured[10] exposure rates are presented for various detector heights in Figures 2 through 6. The values of fluence-to-kerma

Table 1. Operation BREN air and soil constituents with 7% by weight H_2O in soil

Medium	Element	No. Density (Atoms/barn-cm)	Density (g/cc)
Air	H	1.386-7	
	N	3.305-5	1.02-3*
	O	8.921-6	
	Ar	2.149-7	
Soil	H	1.035-2	1.53
	B	8.153-7	
	C	2.789-4	
	N	3.776-5	
	O	3.017-2	
	Na	5.751-4	
	Mg	3.027-4	
	Al	2.336-3	
	Si	9.552-3	
	P	9.818-6	
	S	2.749-5	
	Cl	1.537-5	
	K	7.552-4	
	Ca	3.739-4	
	V	1.140-6	
	Cr	5.103-7	
	Mn	1.020-5	
	Fe	3.520-4	
	Cu	1.387-5	
	Ba	4.574-6	
	Ta	5.468-9	
	W	6.569-8	
	U	1.238-8	
	Ti	4.877-5	

*Read as $1.02*10^{-3}$, applies to Reactor Calculations only; adjusted to 1.01^{-3} g/cc for Co-60 calculations.

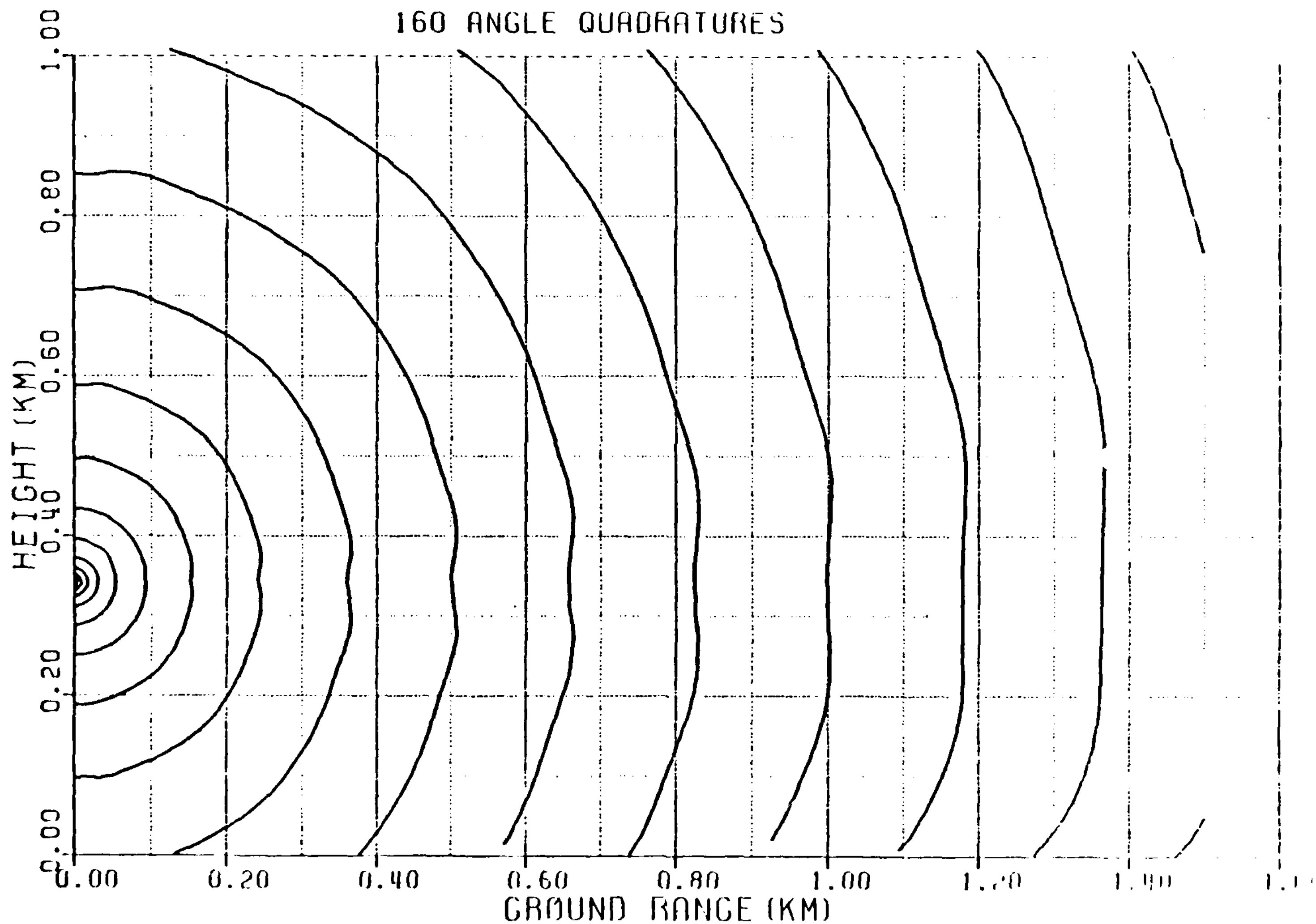


Figure 1. BREN Co-60 calculated exposure rate isocontours.

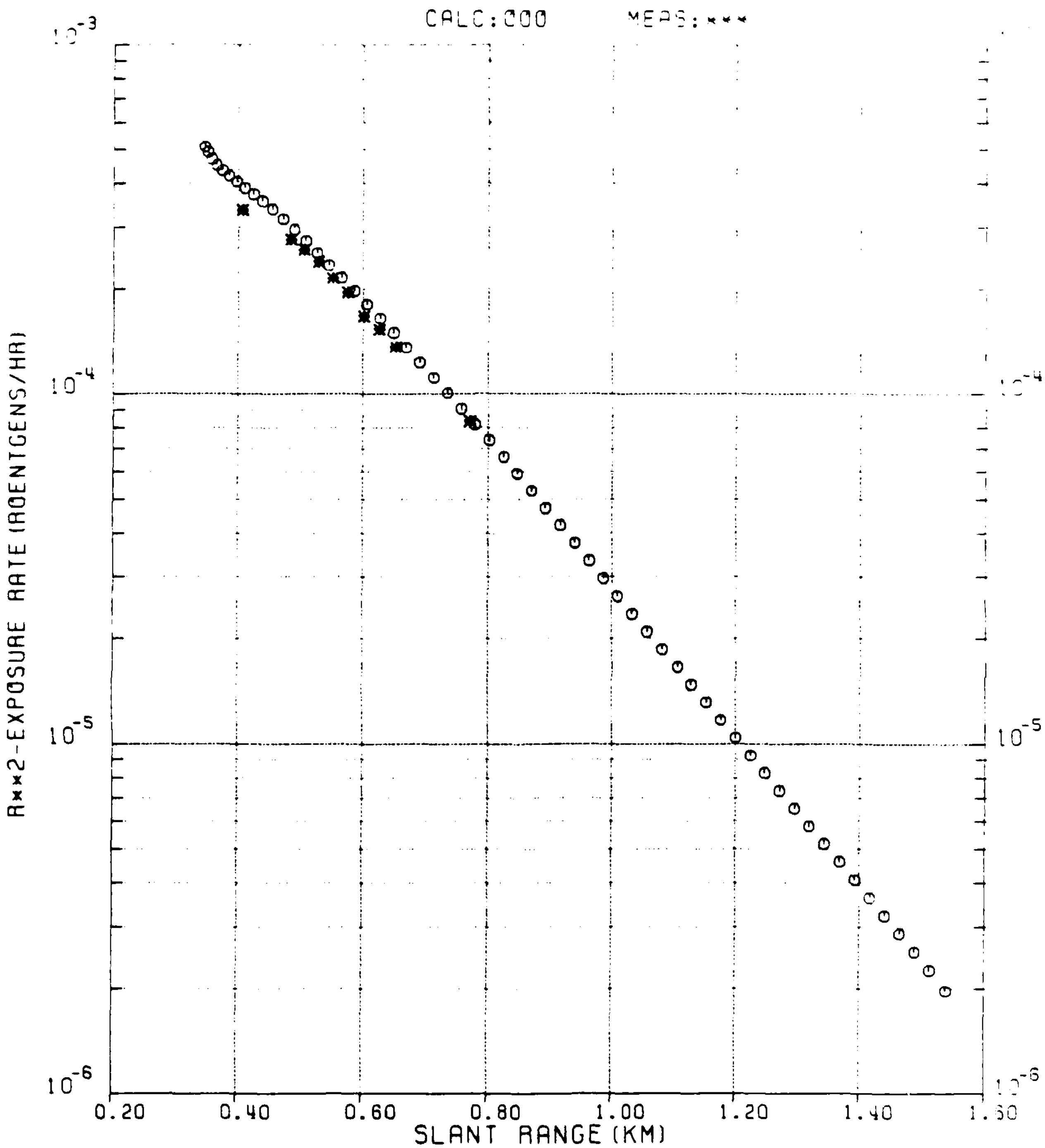


Figure 2. BREN Co-60 exposure rate versus slant range, measured and calculated at the ground surface.

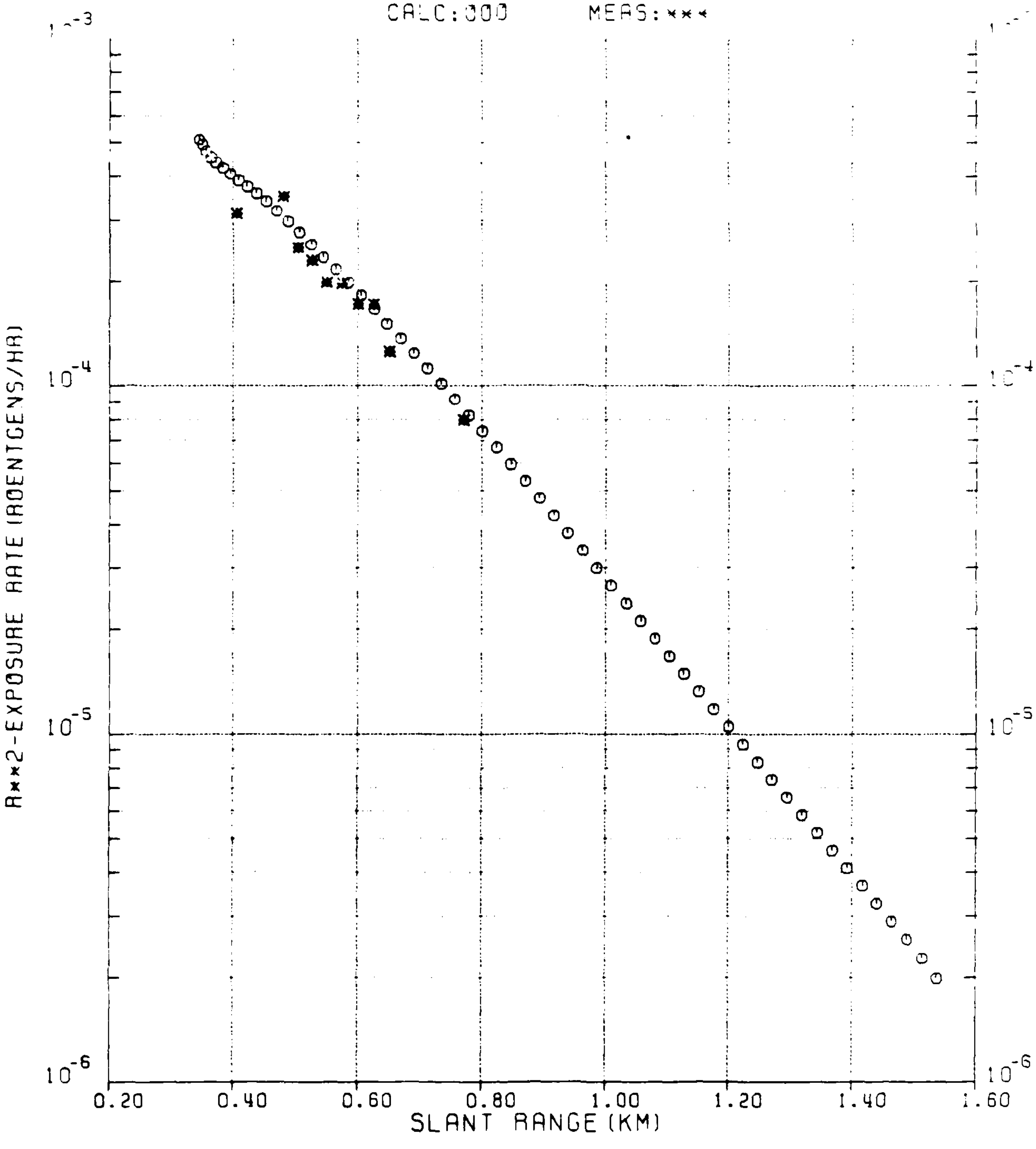


Figure 3. BREN Co-60 exposure rate versus slant range, measured and calculated at 1.5 meters.

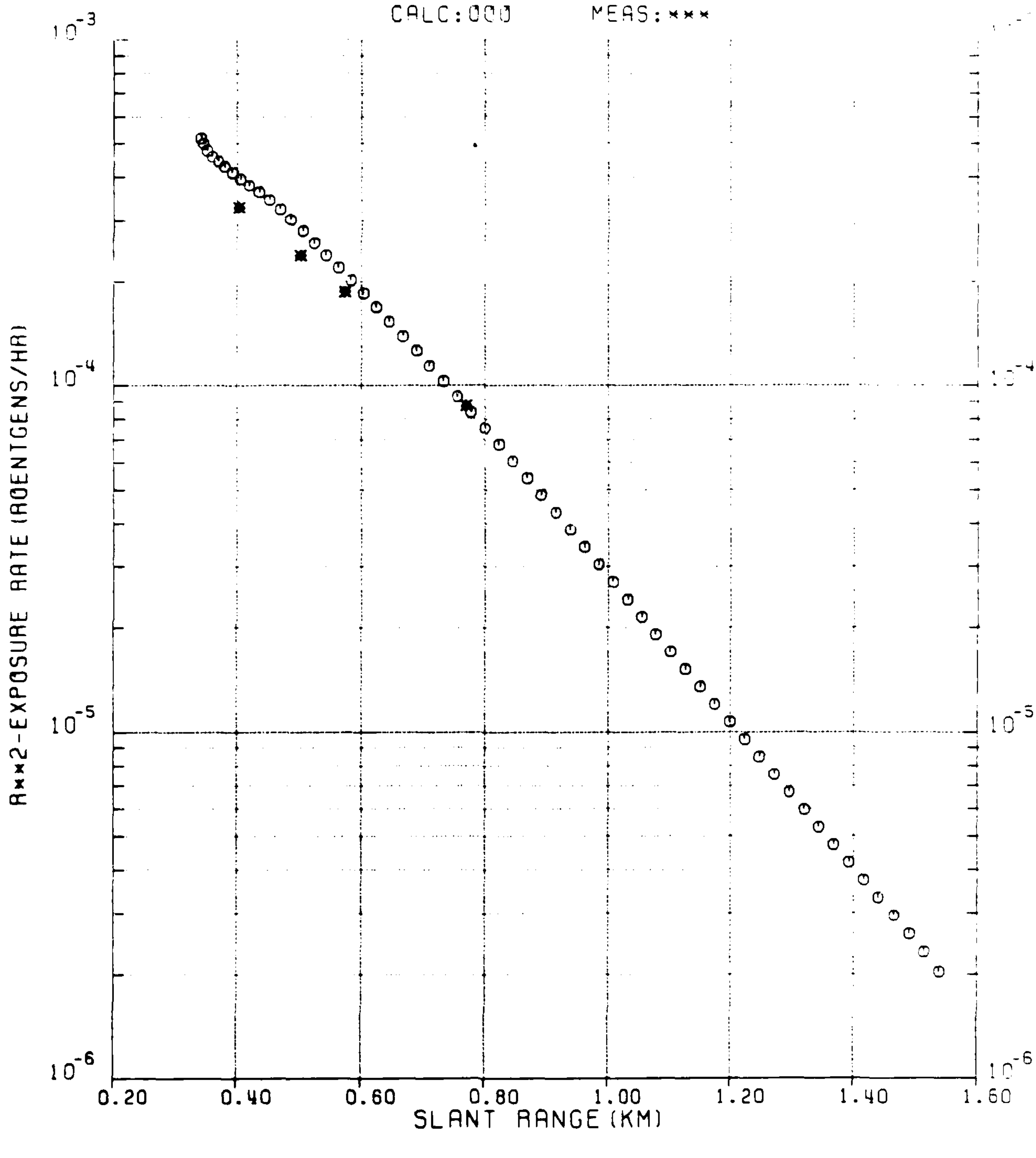


Figure 4. BREN Co-60 exposure rate versus slant range, measured and calculated at 5 meters.

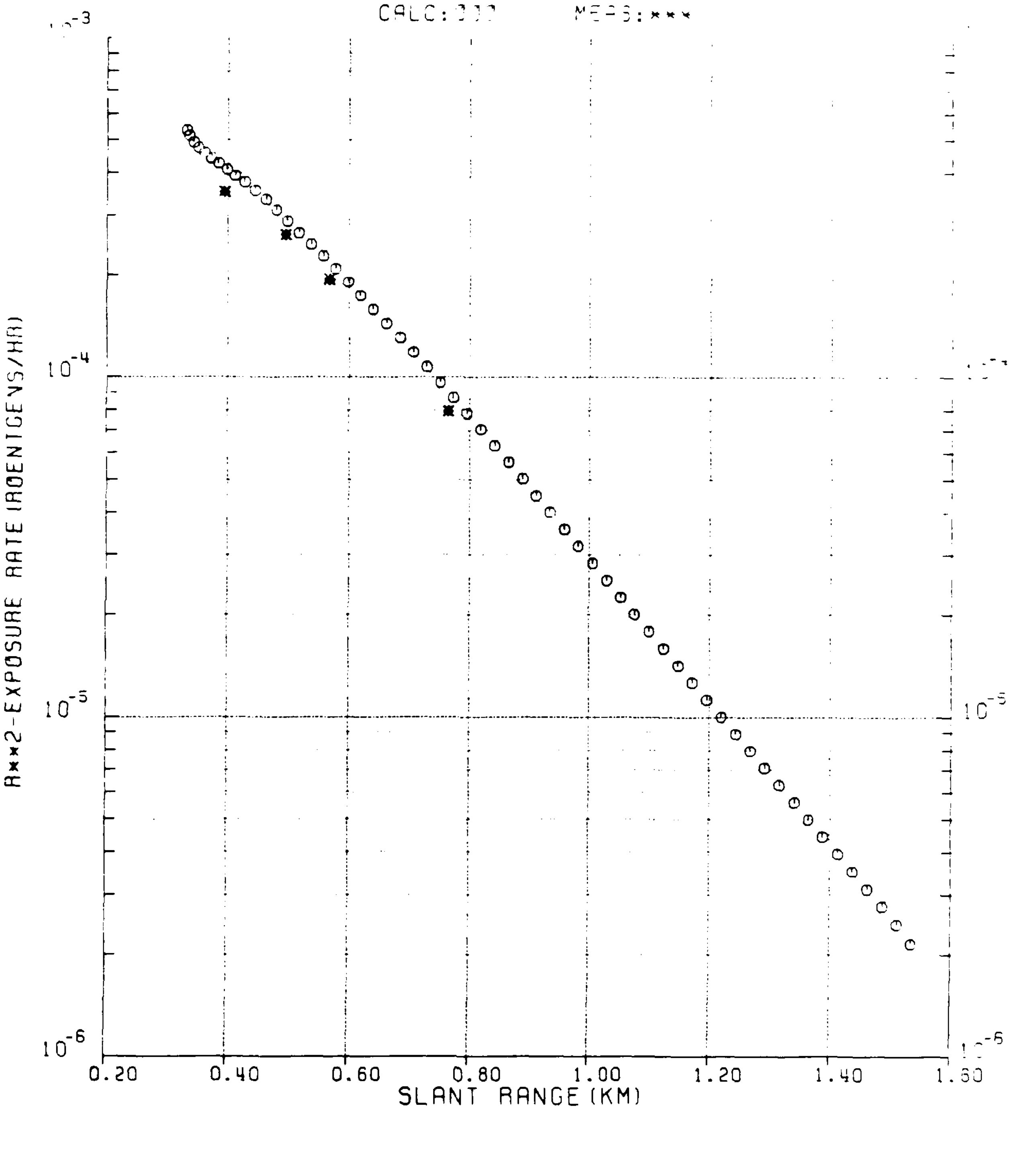


Figure 5. BREN Co-60 exposure rate versus slant range, measured and calculated at 15 meters.

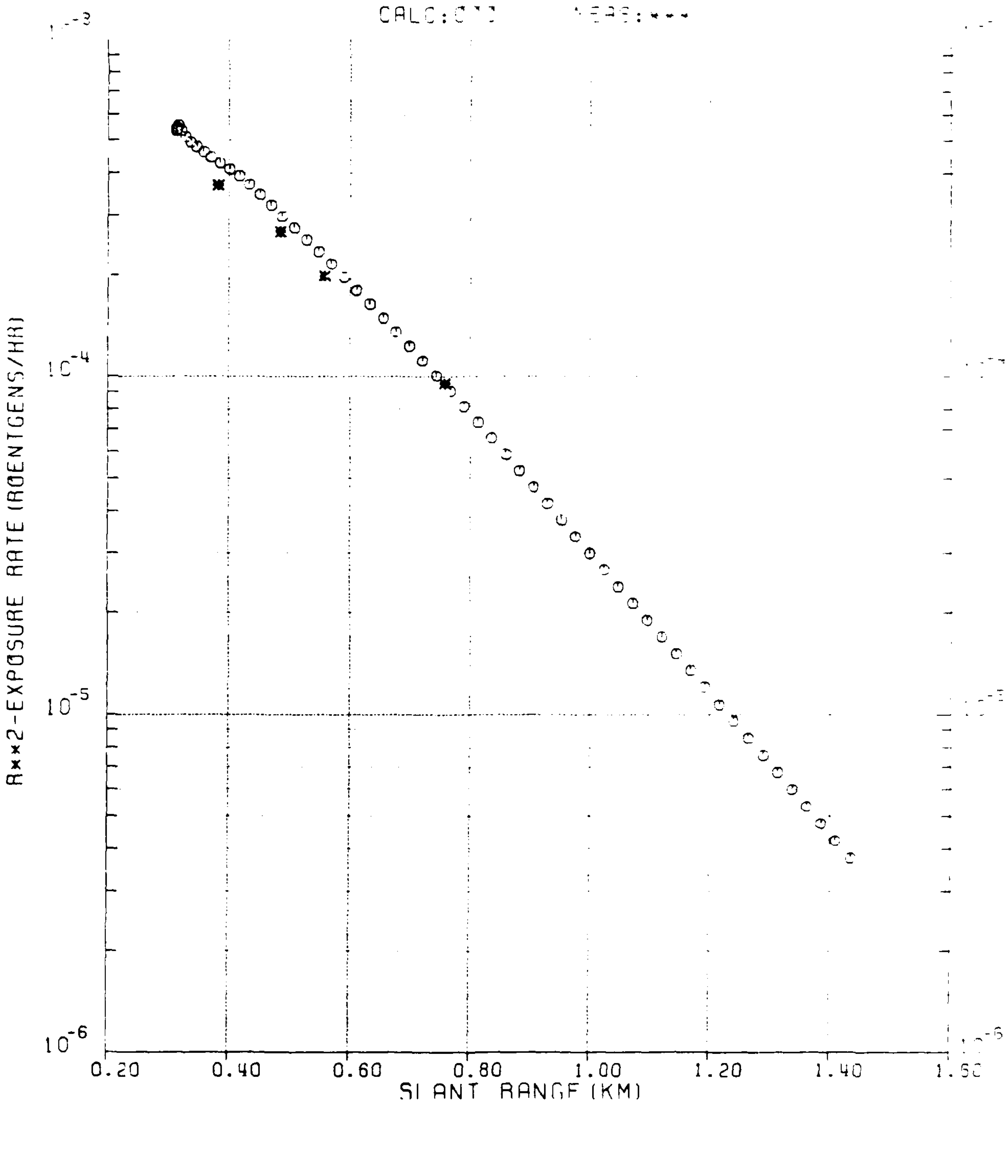


Figure 6. BREN Co-60 exposure rate versus slant range, measured and calculated at 30 meters.

(response) functions used were derived from reference 11 and are presented in Table 2 in the PVC 36 group structure. The agreement between calculated and measured values is shown to be excellent, with discrepancies between the two being generally less than 20%. This excellent agreement is probably due in part to the unambiguous nature of the measured data, i.e., the G-M plateau calibration generally corresponds to the Co-60 gamma ray energy. However, it does engender a high level of confidence in the ability of DOTSAI to properly compute results for transport from a gamma ray point source. The difficulty in producing well behaved results for such a problem has been previously described by Sasamoto and Takeuchi.[12] The results described herein suffered from none of the problems described in that report.

For the purpose of further increasing confidence in DOTSAI results a calculation of the Co-60 experiment was also performed using the DOT-IV(4.2) code (CDC version). This is a more recent DOT variant produced by ORNL and supercedes DOT-III on which DOTSAI is based. In order to use DOT-IV, however, the problem size had to be substantially reduced because of code storage limitations. The maximum possible radial range consistent with a problem height of 1000 meters was found to be 1180 meters (a 50 radial by 75 axial spatial mesh). An additional DOT-IV calculation was performed in which the negative source fix up option (NSF) was invoked. Comparisons between the DOTSAI and DOT-IV computation results showed that the two codes produce identical angular and scalar fluxes when operated in identical modes. Excercising the NSF option in DOT-IV did in fact remove the small positive and negative oscillations in the higher order source moments and in the angular flux. However, the cost of this improvement was substantial, a 30% increase in CPU time. The NSF option did not significantly change the calculated scalar fluence or the integral results.

2.2 REACTOR SOURCE

The BREN reactor may be described as a right circular cylinder of U-235 alloyed 10% by weight with Molybdenum, having an axial dimension of 23 cm and a diameter of 20 cm. The neutron leakage of BREN is taken to be identical to that of the APR reactor, a device of identical material, having axial and radial (diameter) dimensions of 19.8 and 22.6 cm, respectively. Both ORNL and LANL have calculated the neutron leakage from the APR reactor.[13,14] The LANL

Table 2. Gamma ray exposure response functions (roentgens) in the PVC 36 group structure

Group No.	Upper Energy (MeV)	Gamma Ray Exposure (R/Fluence)
1	14.0	3.307-9
2	12.0	2.897-9
3	10.0	2.454-9
4	8.0	2.143-9
5	7.5	2.090-9
6	7.0	2.005-9
7	6.5	1.890-9
8	6.0	1.771-9
9	5.5	1.651-9
10	5.0	1.540-9
11	4.5	1.439-9
12	4.0	1.321-9
13	3.5	1.192-9
14	3.0	1.068-9
15	2.5	9.308-9
16	2.0	8.097-10
17	1.66	7.273-10
18	1.5	6.733-10
19	1.33	5.797-10
20	1.0	4.693-10
21	8.0-1	4.001-10
22	7.0-1	3.524-10
23	6.0-1	3.026-10
24	5.12-1	2.827-10
25	5.1-1	2.646-10
26	4.5-1	2.337-10
27	4.0-1	1.891-10
29	3.0-1	1.333-10
29	2.0-1	8.539-11
30	1.5-1	5.584-11
31	1.0-1	3.792-11
32	7.5-2	3.396-11
33	6.0-2	3.628-11
34	4.5-2	5.700-11
35	3.0-2	1.268-10
36	2.0-2	4.429-10

spectrum was chosen over that of ORNL for use in the calculation reported here and is presented in Table 3. The LANL spectrum was chosen partially on the basis of comparisons of both spectra with that measured at BREN using threshold foils[8] as follows:

Energy Range (MeV)	Neutron Source Fraction		
	Meas.	LANL	ORNL
E>2.5	.206	.204	.168
1.5<E<2.5	.126	.185	.168
.75<E<1.5	.294	.248	.238
.01<E<.75	.374	.363	.426

The neutron source normalization was calculated according to the sulphur neutron monitor results reported for BREN.[8] These fluence measurements, 28.5 inches from the axis at midplane, integrated over 4π steradians, give a E>2.5MeV source of $2.92 * 10^{16}$ neutrons per Kw-hr. This number, divided by the LANL source fraction above 2.5 MeV, results in $1.43 * 10^{17}$ total leakage neutrons per Kw-hr or 1.28 neutrons leaking per fission. This number agrees very well with the results of later measurements performed on HPRR by Johnson and Poston[15], which stipulated the leakage to be 1.31 neutrons per fission. These measurements were also performed at the reactor midplane.

The 1.28 neutrons per fission normalization has been modified to 1.10 according to recent information provided by H. Kazi, APRD.[16] Sulfur foil measurements about the polar axis of the APR reactor indicate that the total leakage estimated on the basis of midplane measurements alone results in a source which is too large by 16.4%, assuming that the neutron leakage of the device is everywhere proportional to that greater than 2.5 MeV. All results shown in this report reflect the revised 4π integral leakage value of 1.10 neutrons per fission.

The LANL calculation did not include gamma rays. Therefore, the reactor gamma ray source spectrum in Table 3 is that calculated by ORNL for APR and incorporates a normalization factor of .65 photons per source neutron. The gamma ray leakage is assumed to be isotopic.

Table 3. BREN/APR source spectrum in the DLC31 group structure ($1n + .65\gamma = 1.65$ source particles per source neutron)

Upper Group No.		Energy (MeV)	Source Fraction
1	Neutrons	19.64	3.781-7*
2		16.90	1.286-5
3		14.92	2.370-5
4		14.19	7.986-6
5		13.84	5.849-5
6		12.84	6.362-5
7		12.21	2.354-4
8		11.05	5.131-4
9		10.0	1.066-3
10		9.048	2.001-3
11		8.187	3.258-3
12		7.408	7.645-3
13		6.376	2.450-2
14		4.965	6.862-3
15		4.724	2.574-2
16		4.066	7.296-2
17		3.012	7.386-2
18		2.385	1.136-2
19		2.307	8.338-2
20		1.827	1.903-1
21		1.108	2.390-1
22		.5502	2.144-1
23		.1576	1.881-2
24		.1111	1.753-2
25		5.248-2	4.896-3
26		2.479-2	3.066-4
27		2.188-2	8.517-4
28		1.033-2	2.303-4
29		3.355-3	1.504-5
30		1.234-3	7.318-7
31		5.829-4	1.203-6
32		1.013-4	0.0
33		2.902-5	0.0

*Read as 3.781×10^{-7}.

Table 3. BREN/APR source spectrum in the DLC31 group structure (continued) (1n + .65γ = 1.65 source particles per source neutron)

Group No.	Upper Energy (MeV)	Source Fraction
34	1.063-5	0.0
35	3.059-5	0.0
36	1.125-6	0.0
37	4.140-7	0.0
38 Gamma Rays	14.0	2.600-4
39	14.0	2.340-3
40	8.0	2.210-3
41	7.0	2.340-3
42	6.0	4.485-3
43	5.0	1.008-2
44	4.0	2.054-2
45	3.0	2.334-2
46	2.5	3.920-2
47	2.0	7.657-2
48	1.5	1.345-1
49	1.0	1.177-1
50	7.0-1	1.121-1
51	4.5-1	6.162-2
52	3.0-1	3.699-2
53	1.5-1	4.680-3
54	1.0-1	1.040-3
55	7.0-2	1.300-4
56	4.5-2	0.0
57	3.0-2	0.0
58	2.0-2	0.0
Total		1.65

Calculations of BREN reactor radiation fields were performed using the DLC31 cross section library[17] sponsored by the Defense Nuclear Agency. The library features 1/E weighted cross sections for a large number of materials in a 37 neutron, 21 gamma ray group format, offering P_3 Legendre expansion to describe angular scattering. The library also contains nitrogen and oxygen cross sections that have been weighted by a transported fission spectrum. These were used along with the 1/E weighted data to depict the atmospheric and ground constituent cross sections, respectively.

The BREN geometry was modeled for DOTSAI with 83 radial and 74 axial meshes in cylindrical coordinates. The radial and axial boundaries were at 2000 and 1000 meters, respectively. No albedos were used in the calculation. The soil thickness was chosen to be 1 meter. Dry air with a density of 1.018 g/l, plus 0.2% moisture, was chosen for the computation, this provides a total air density of 1.02 g/l and corresponds to conditions to which reported measurements were standardized.[8] The soil constituents were the same as those for the Co-60 calculations. The soil water content was taken to be 7% by weight, corresponding to a value observed at the midpoint of the reactor experiment series.[18] Table 1 lists the air and soil elemental composition used in the BREN reactor calculations.

The BREN reactor was treated as a point source of neutrons and gamma rays at 342.9 meters above the ground surface. The point source was converted to a volume distributed source via the analytical first collision source option in DOTSAI. Initially, a P_3, S_8 (48 angle) calculation was performed. However, this was found to produce gamma ray transport results which suffered substantially from ray effects. It was concluded that such effects were not ameliorated by the first collision source because gamma rays causing them were produced by neutron interaction in the air and ground, near and below the source, respectively. In order to decrease the ray effect problem the angular fluxes were converted to a 160 angle (S_{16}) quadrature set and the problem was restarted with that set. The gamma rays were run to convergence. However, the neutrons were allowed to proceed only one iteration to conserve computer time. The S_8-S_{16} conversion made no substantial difference to the neutron transport. However, a significant improvement in the gamma ray distribution was obtained. Even so, some evidence of ray effects still remained.

Table 4. Four element (Caswell) tissue neutron kerma factors (rad) truncated at 170 Kev and gamma ray exposure intensity (roentgen) in the DLC-31, 37 neutron - 21 gamma ray group structure

Group No.	Upper Energy (MeV)	Neutron kerma (Rads/fluence)	Group No.	Upper Energy (MeV)	Gamma Ray kerma (R/fluence)
1	19.64	7.59-9*	1	14.0	3.102-9
2	16.90	7.16-9	2	10.0	2.453-9
3	14.92	6.87-9	3	8.0	2.117-9
4	14.19	6.74-9	4	7.0	1.948-9
5	13.84	6.52-9	5	6.0	1.711-9
6	12.84	6.24-9	6	5.0	1.490-9
7	12.21	6.16-9	7	4.0	1.257-9
8	11.05	5.78-9	8	3.0	1.068-9
9	10.0	5.53-9	9	2.5	9.308-10
10	9.048	5.27-9	10	2.0	7.834-10
11	8.187	5.11-9	11	1.5	6.115-10
12	7.408	4.95-9	12	1.0	4.462-10
13	6.376	4.62-9	13	7.0-1	3.132-10
14	4.965	4.38-9	14	4.50-1	2.039-10
15	4.724	4.31-9	15	3.0-1	1.173-10
16	4.066	4.07-9	16	1.5-1	5.584-11
17	3.012	3.44-9	17	1.0-1	3.738-11
18	2.385	3.15-9	18	7.0-2	3.520-11
19	2.307	3.11-9	19	4.5-2	5.700-11
20	1.827	2.69-9	20	3.0-2	1.268-10
21	1.108	2.05-9	21	2.0-2	4.429-10
22	.5502	1.27-9			
23	.1576	0.0			
24	.1111	0.0			
25	5.248-2	0.0			
26	2.479-2	0.0			
27	2.188-2	0.0			
28	1.033-2	0.0			
29	3.355-3	0.0			
30	1.234-3	0.0			
31	5.829-4	0.0			
32	1.013-4	0.0			
33	2.902-5	0.0			
34	1.068-5	0.0			
35	3.059-6	0.0			
36	1.125-6	0.0			
37	4.140-7	0.0			

*Read as $7.59*10^{-9}$.

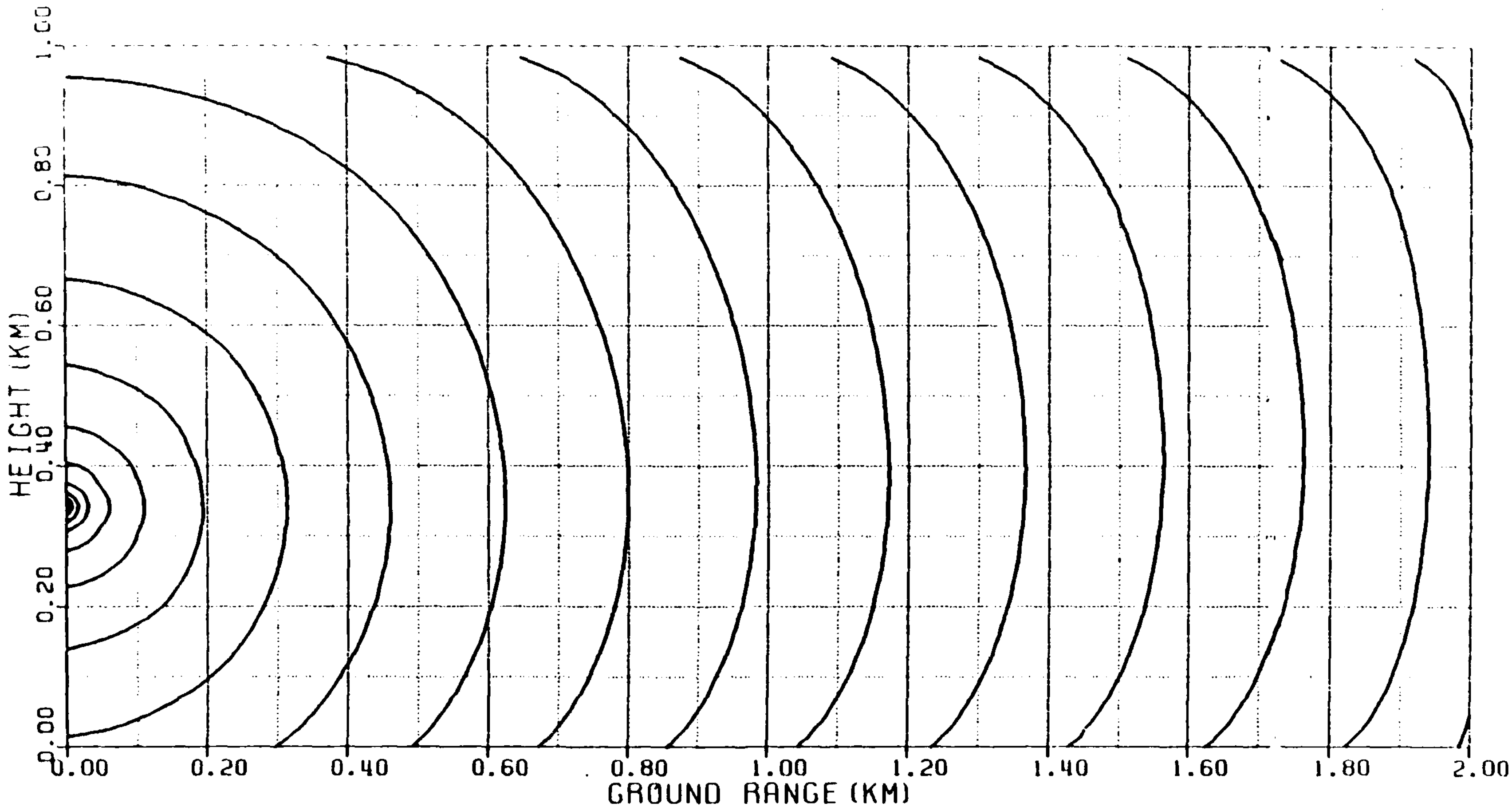


Figure 7. BREN reactor calculated neutron kerma rate isocontours.

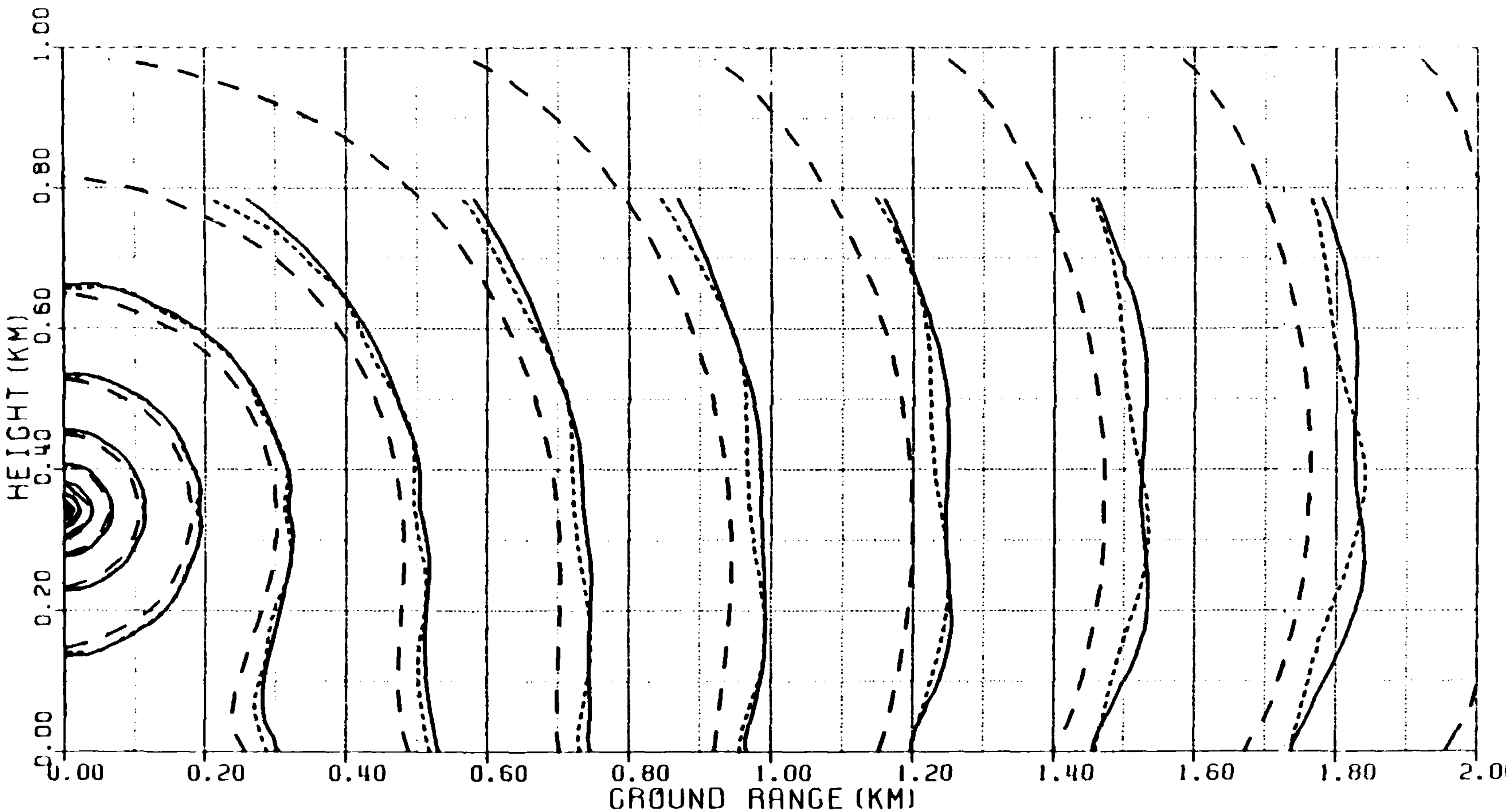


Figure 8. BREN reactor calculated gamma ray kerma rate isocontours for 48, 160, amd 240 angle quadratures.

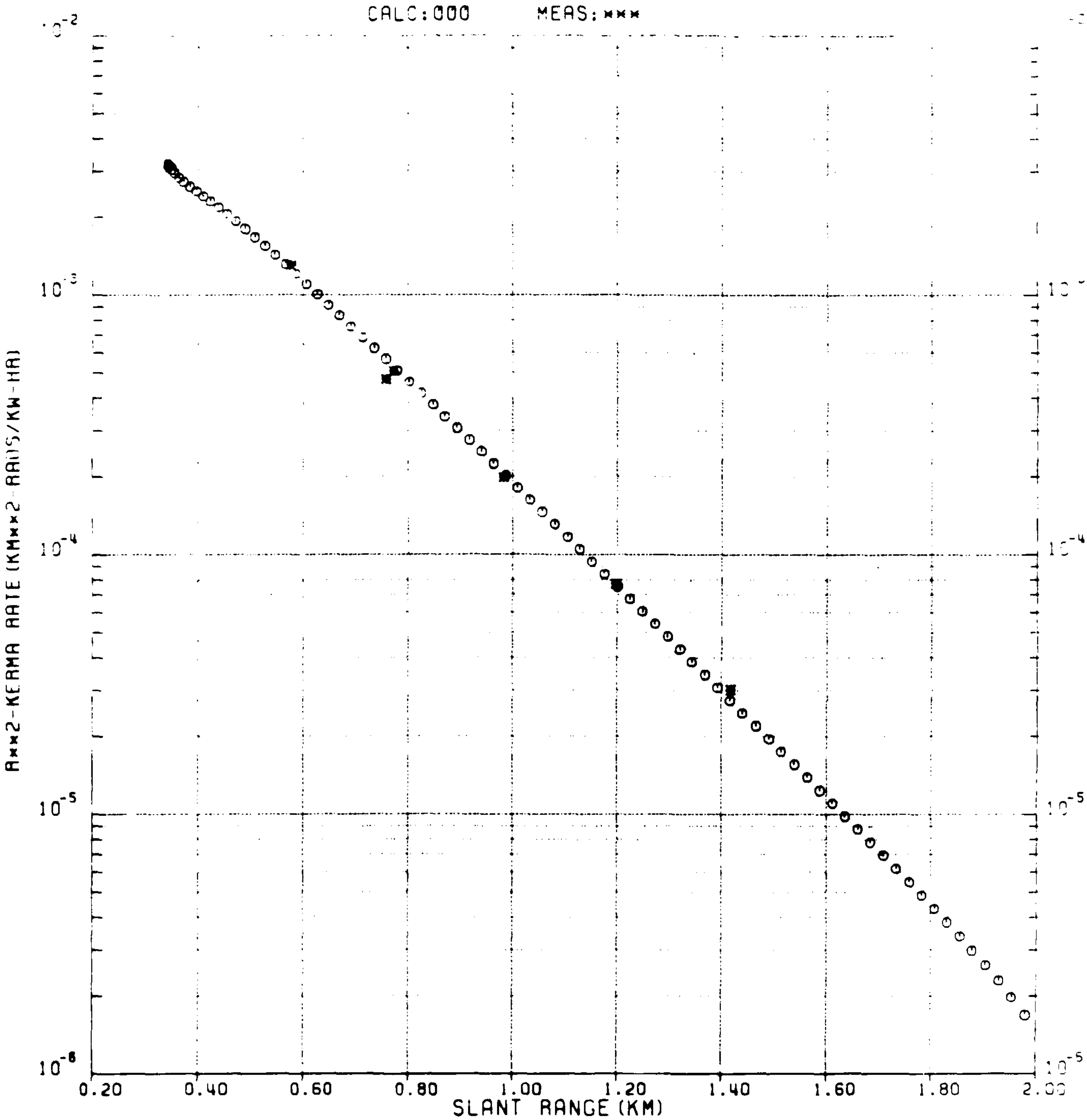


Figure 9. BREN reactor neutron kerma rate versus slant range measured and calculated at the ground surface.

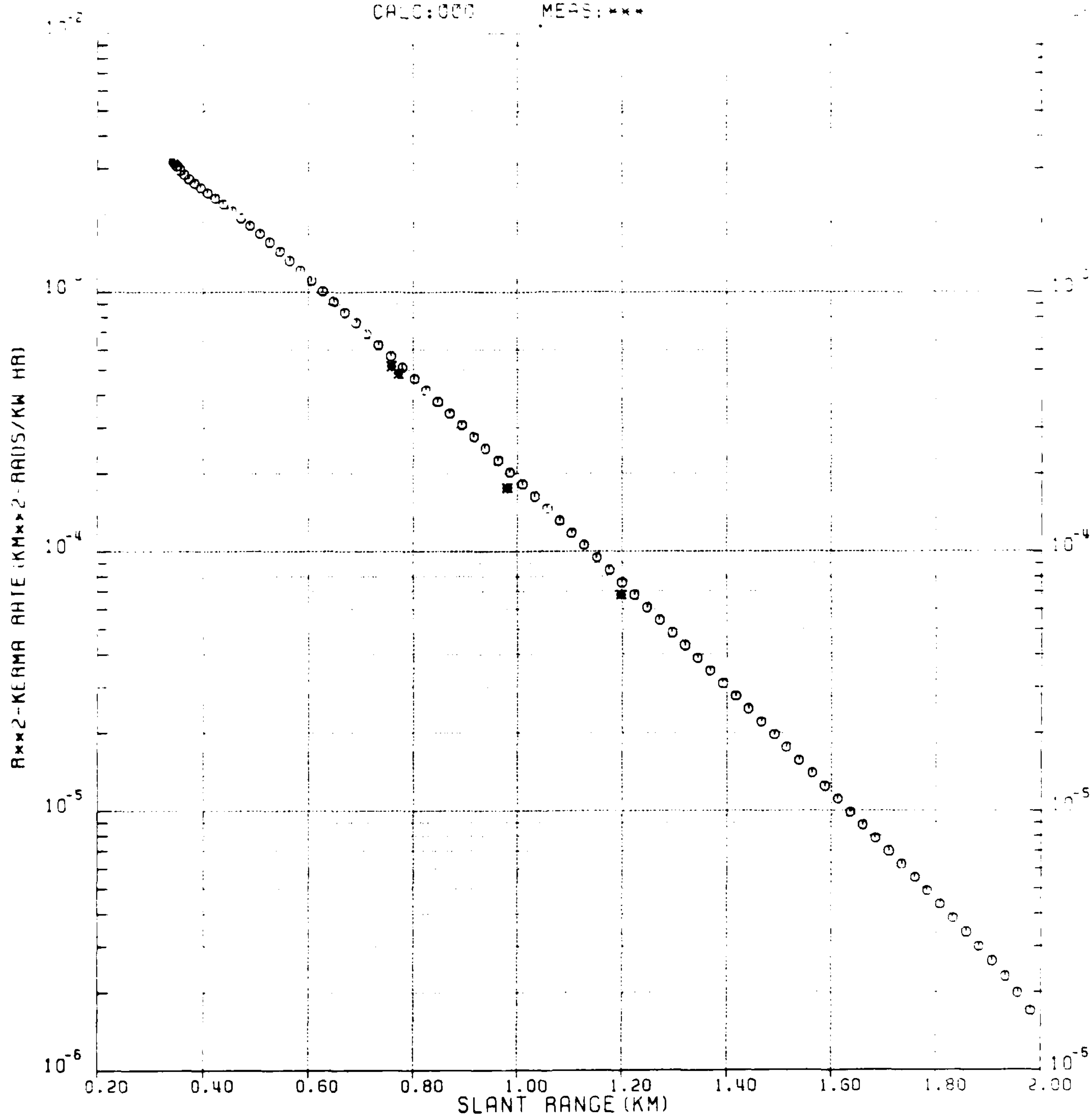


Figure 10. BREN reactor neutron kerma rate versus slant range measured and calculated at 0.9 meters.

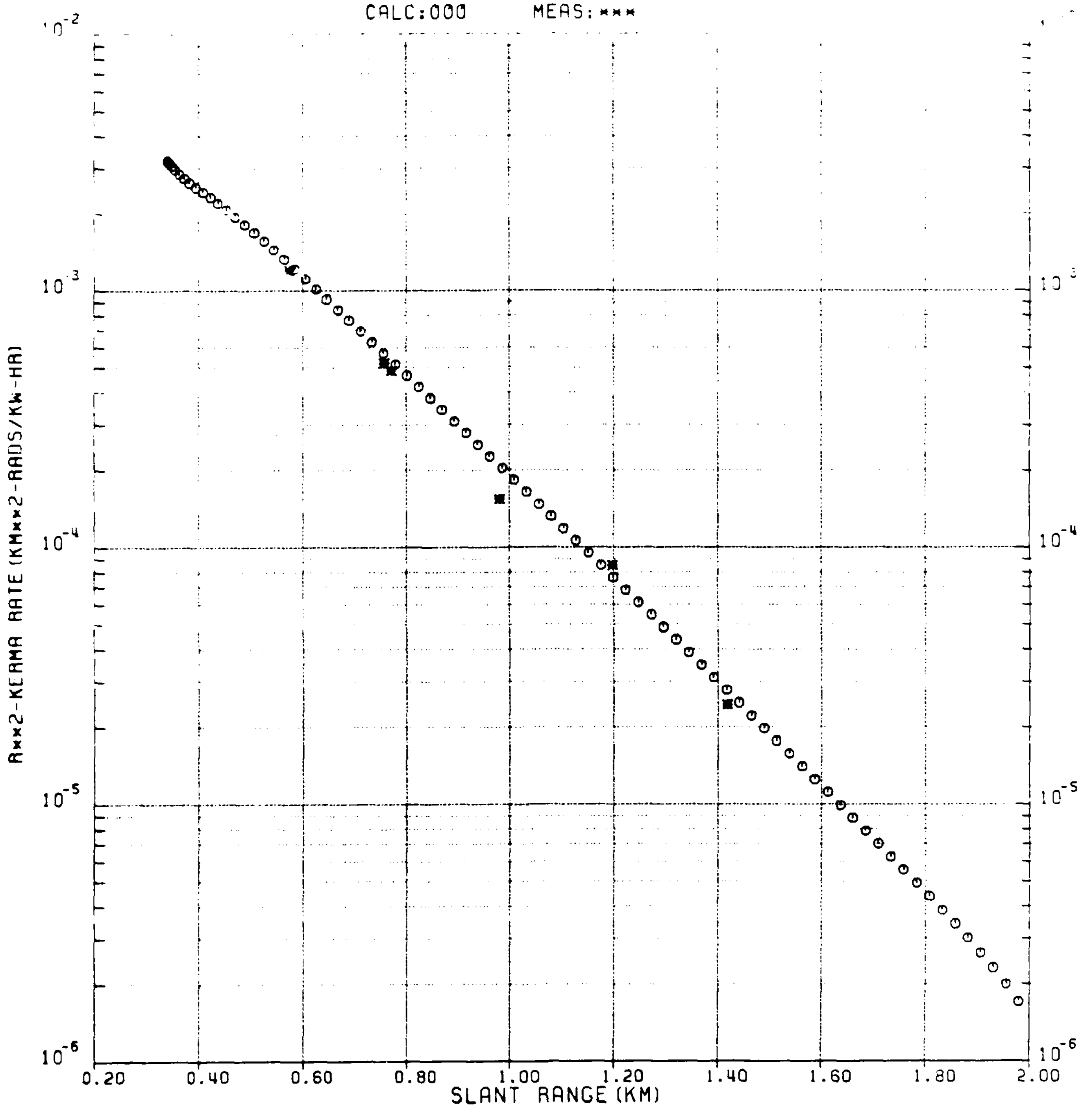


Figure 11. BREN reactor neutron kerma rate versus slant range measured and calculated at 1.5 meters.

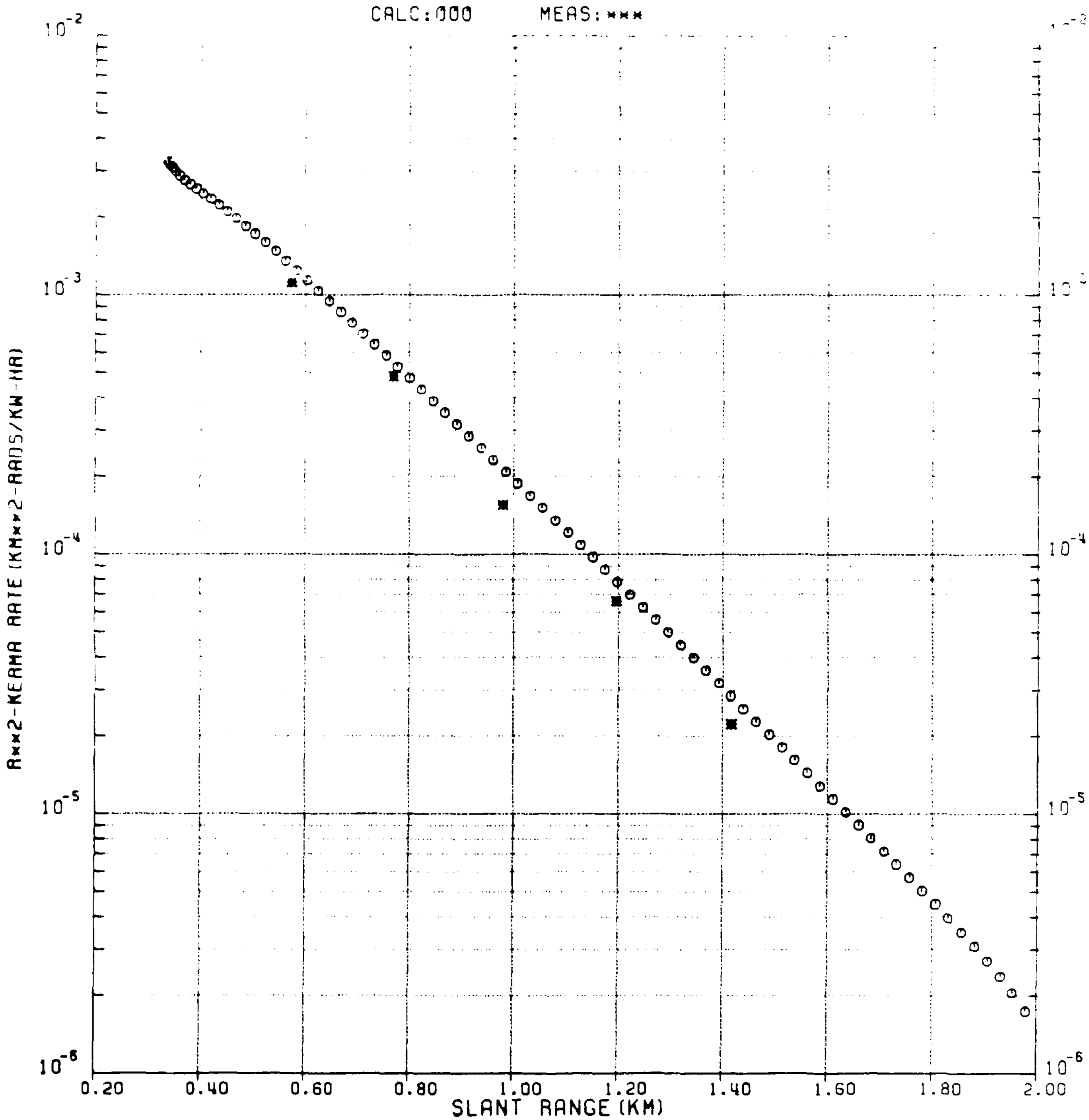


Figure 12. BREN reactor neutron kerma rate versus slant range measured and calculated at 5 meters.

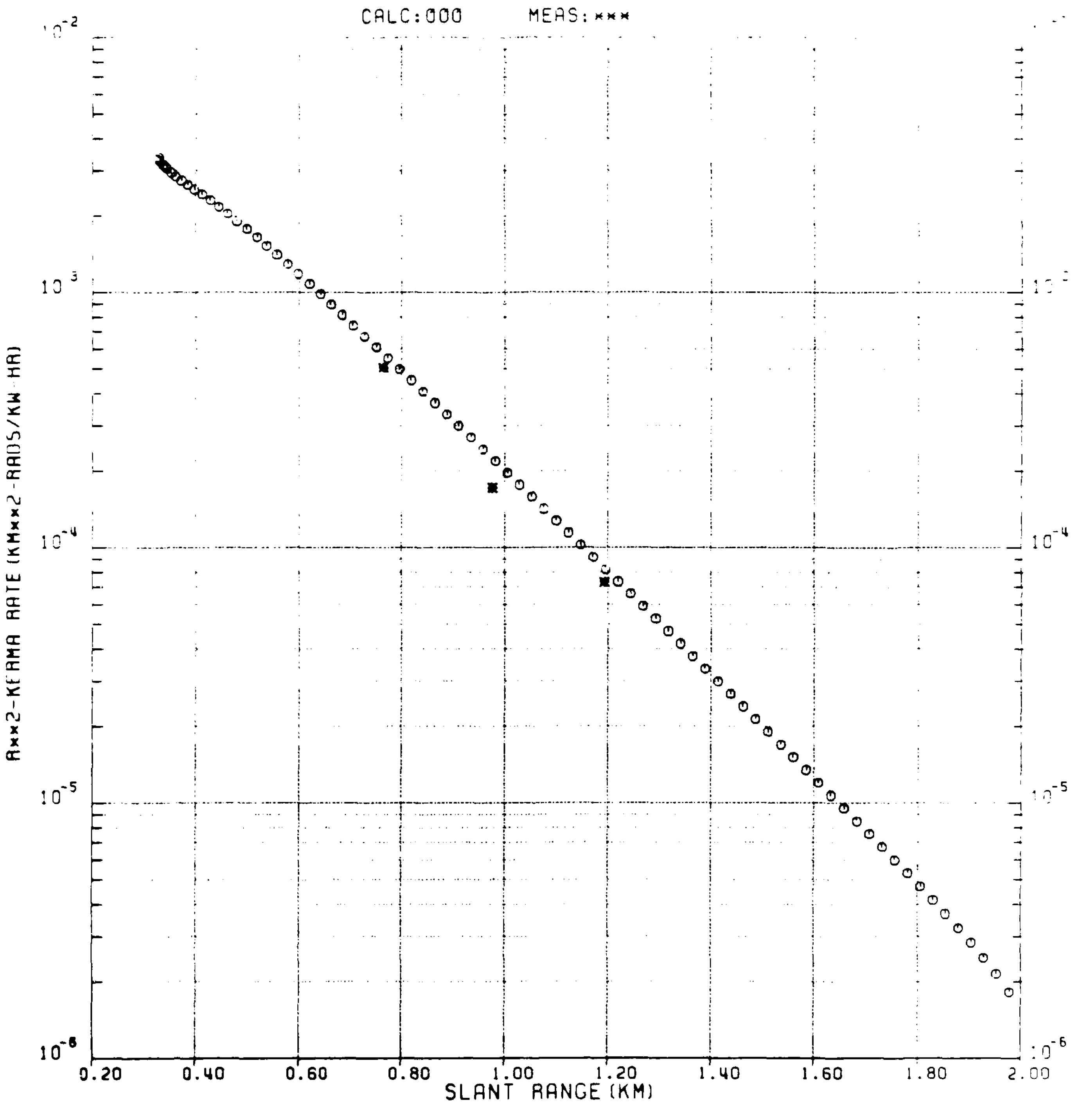


Figure 13. BREN reactor neutron kerma rate versus slant range measured and calculated at 15 meters.

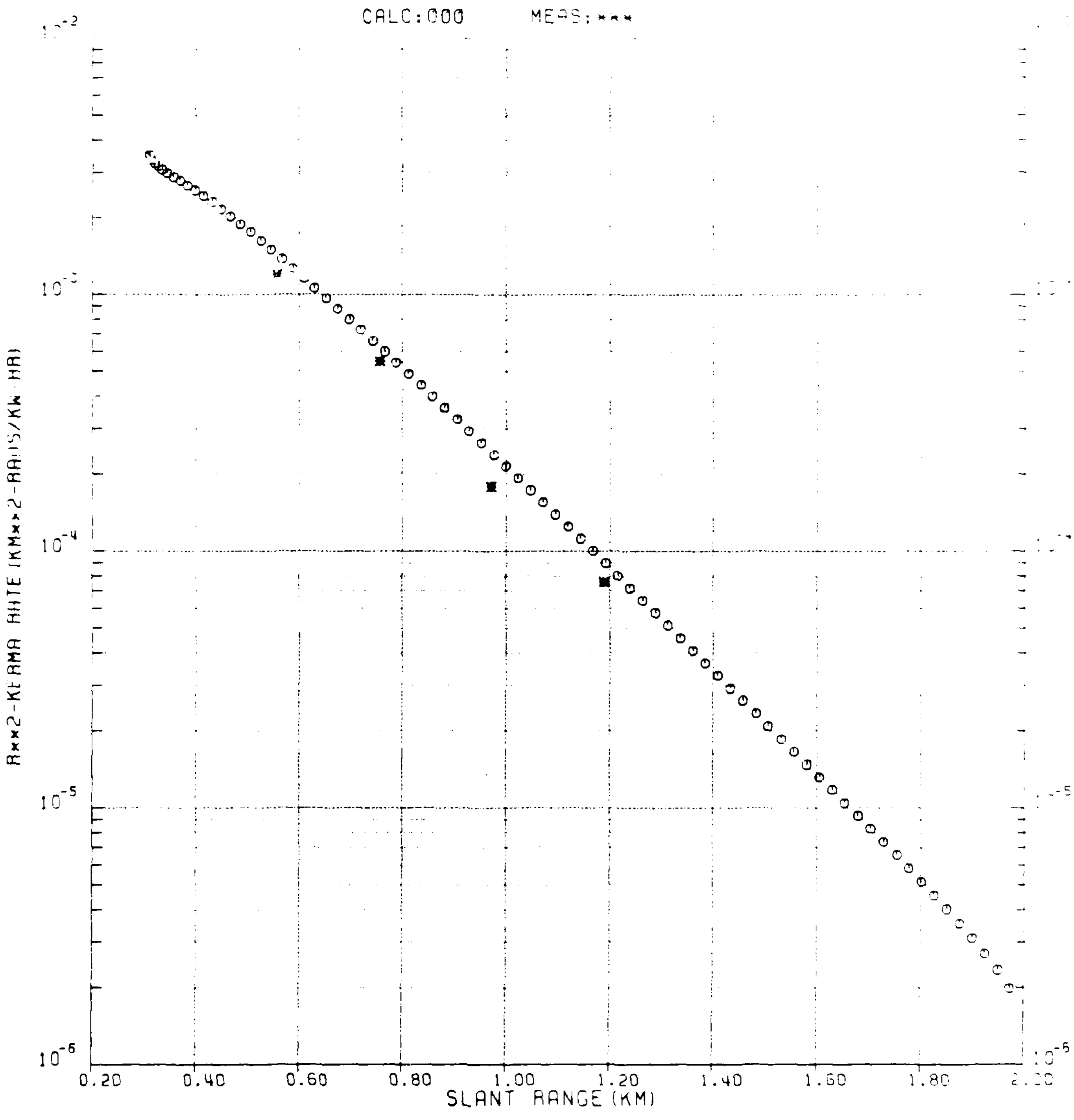


Figure 14. BREN reactor neutron kerma rate versus slant range measured and calculated at 30 meters.

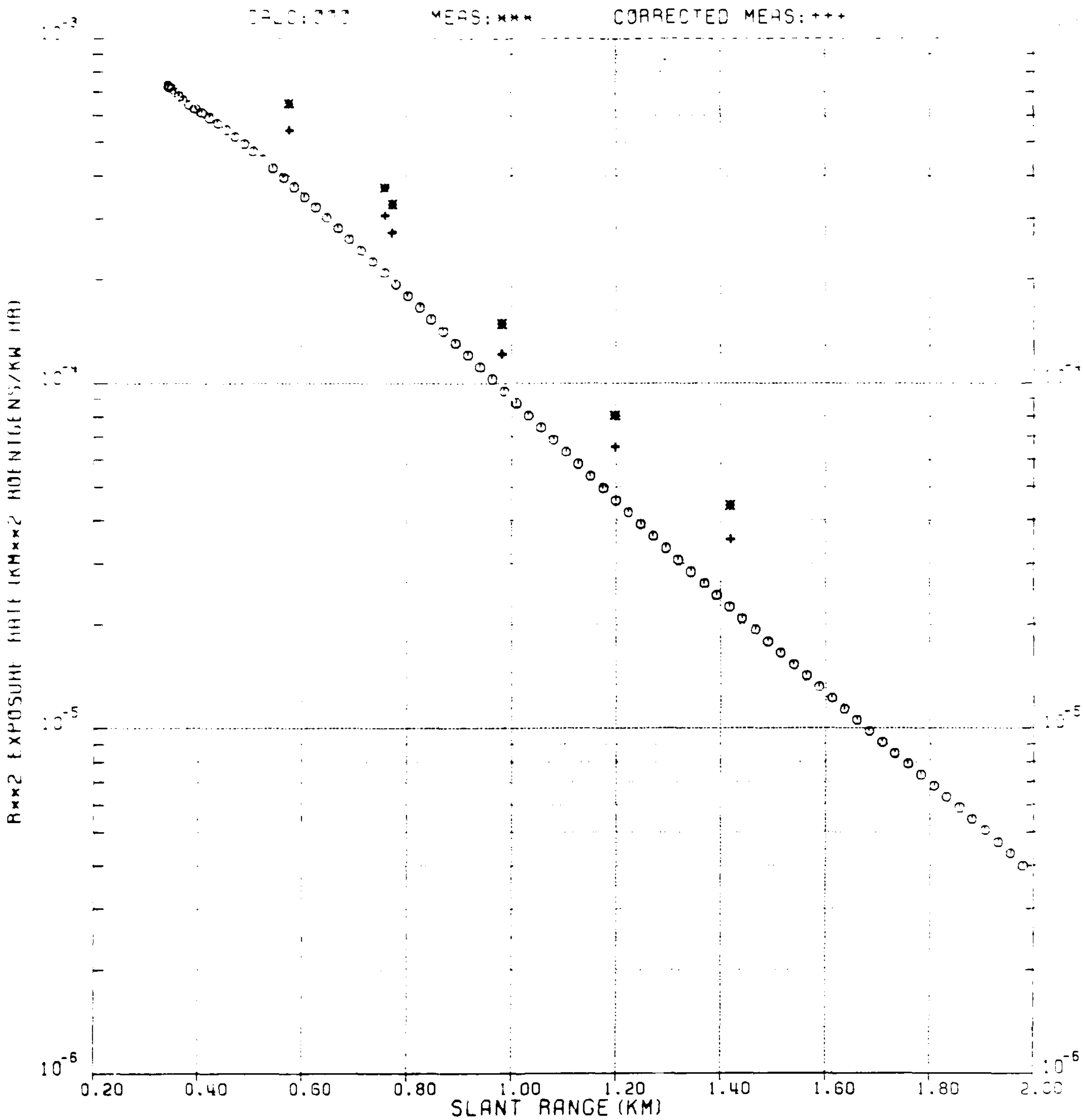


Figure 15. BREN reactor gamma ray kerma rate versus slant range measured and calculated at ground surface.

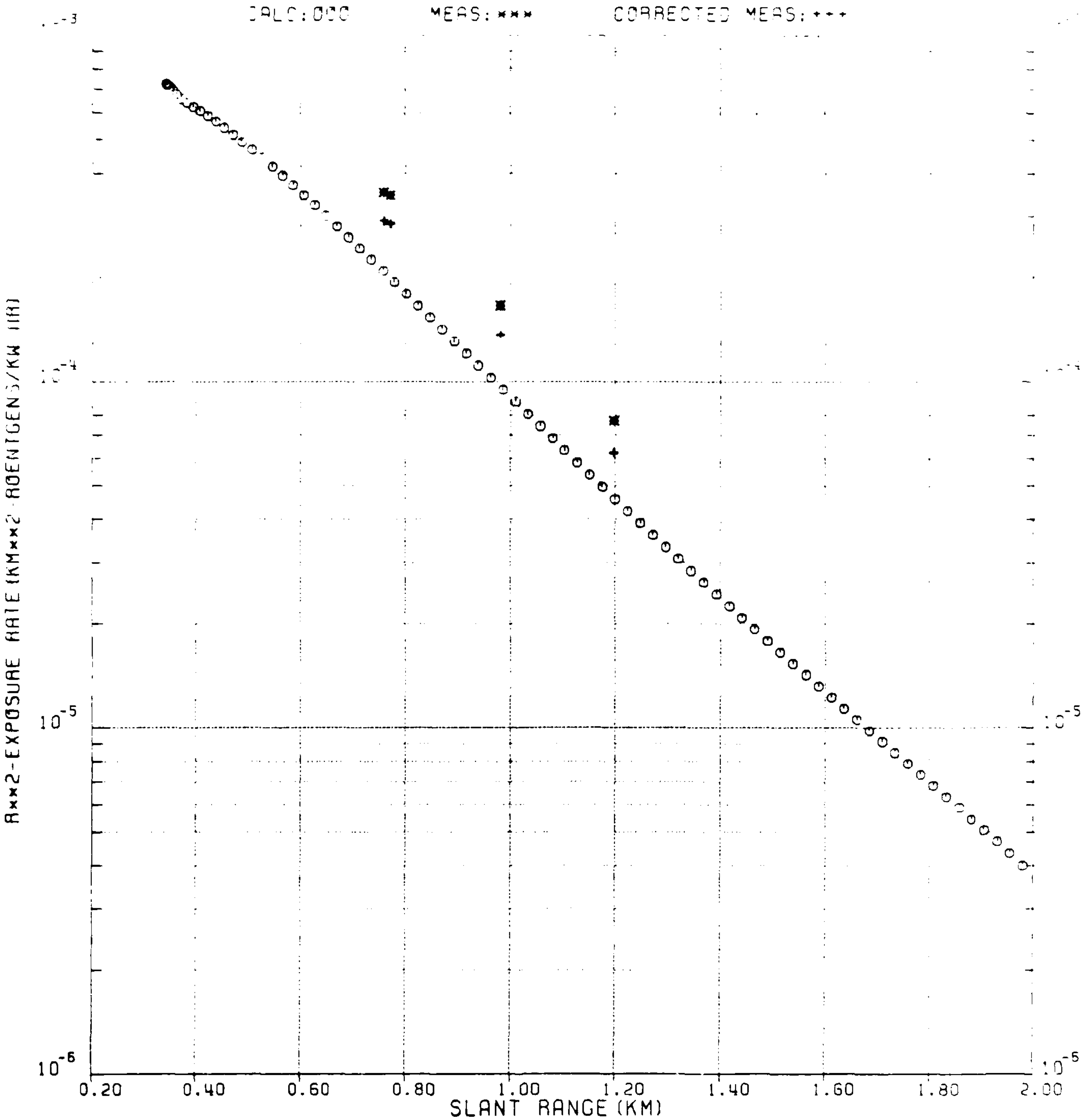


Figure 16. BREN reactor gamma ray kerma rate versus slant range measured and calculated at 0.9 meters.

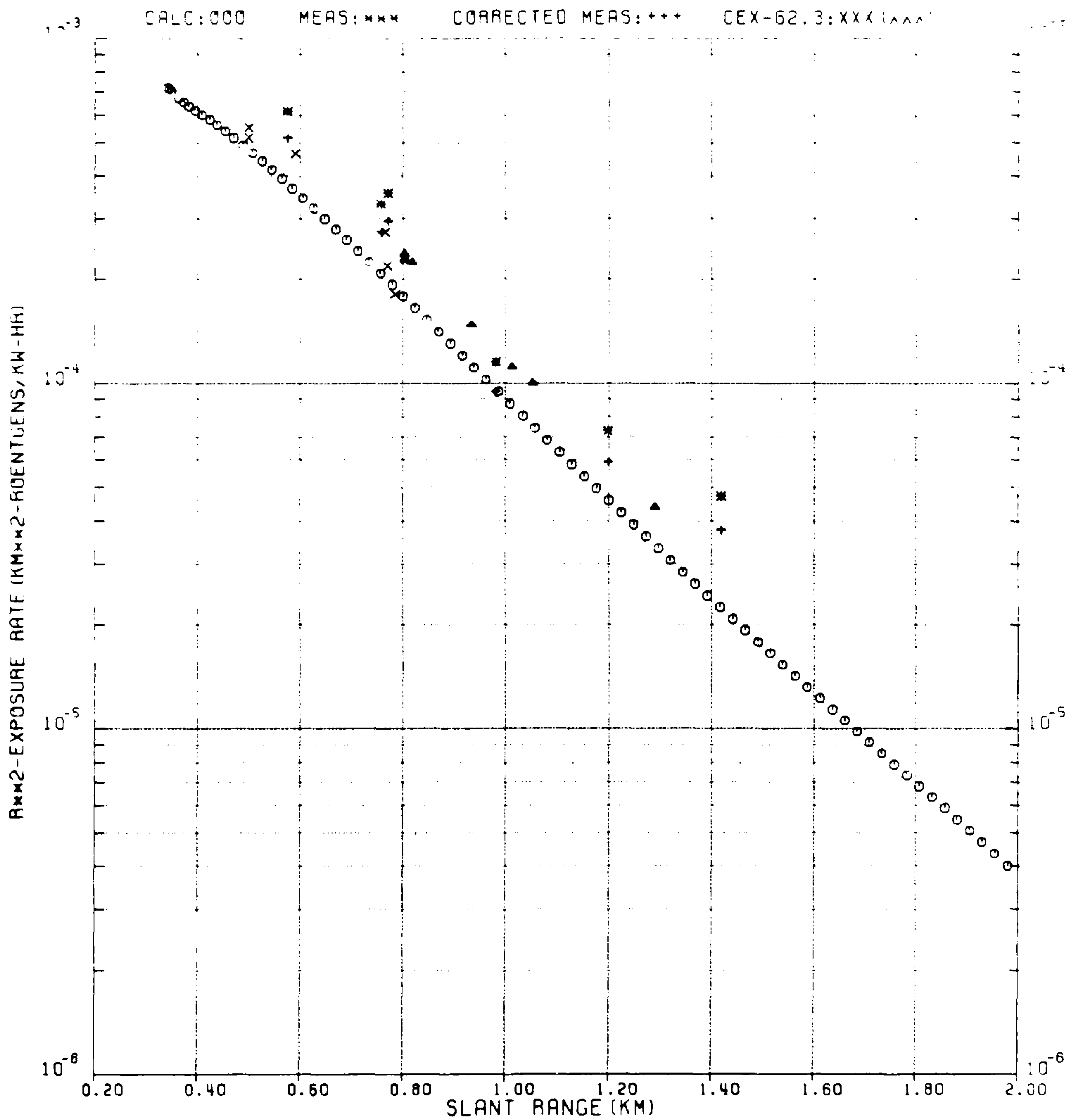


Figure 17. BREN reactor gamma ray kerma rate versus slant range measured and calculated at 1.5 meters.

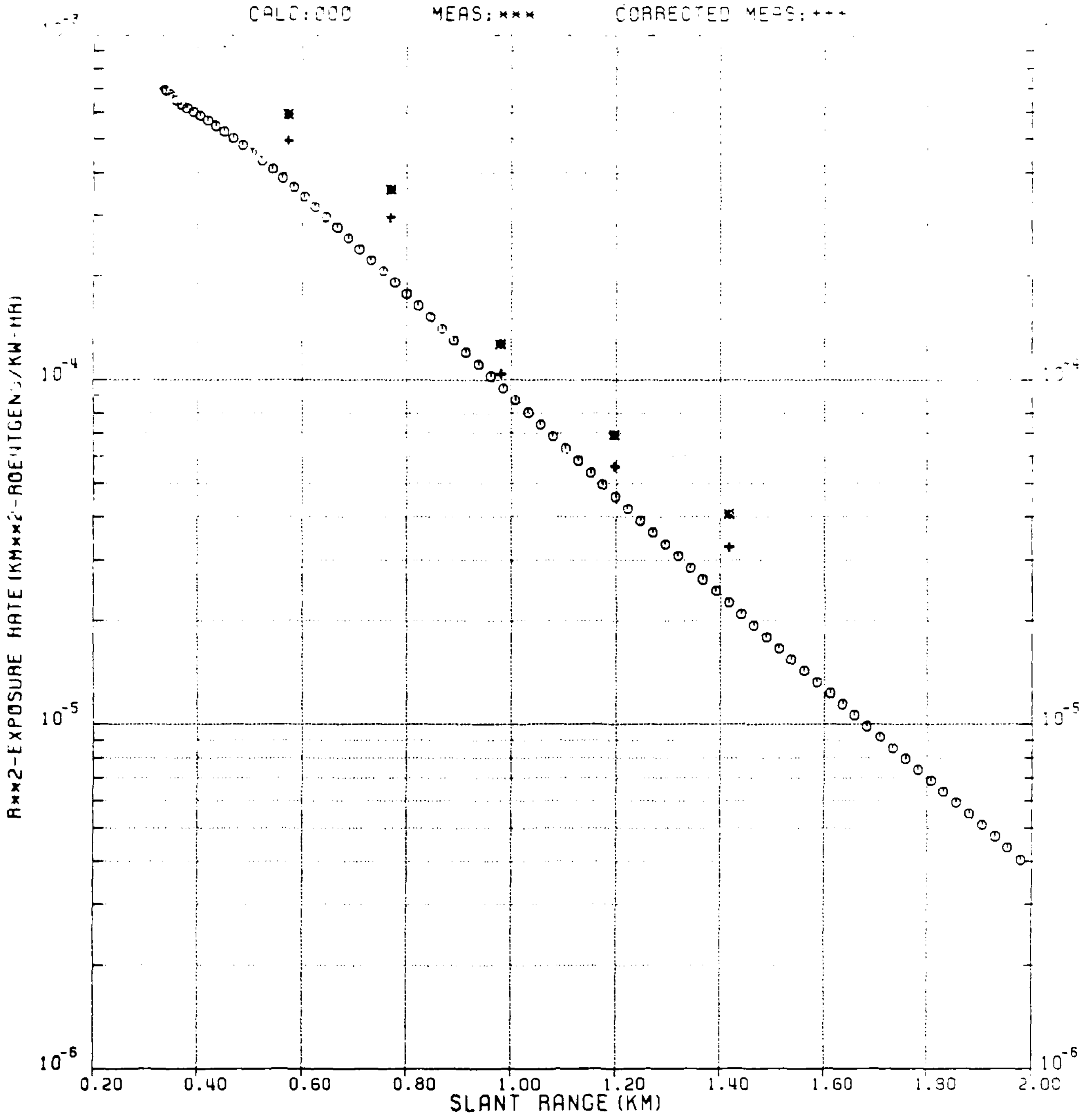


Figure 18. BREN reactor gamma ray kerma rate versus slant range measured and calculated at 5 meters.

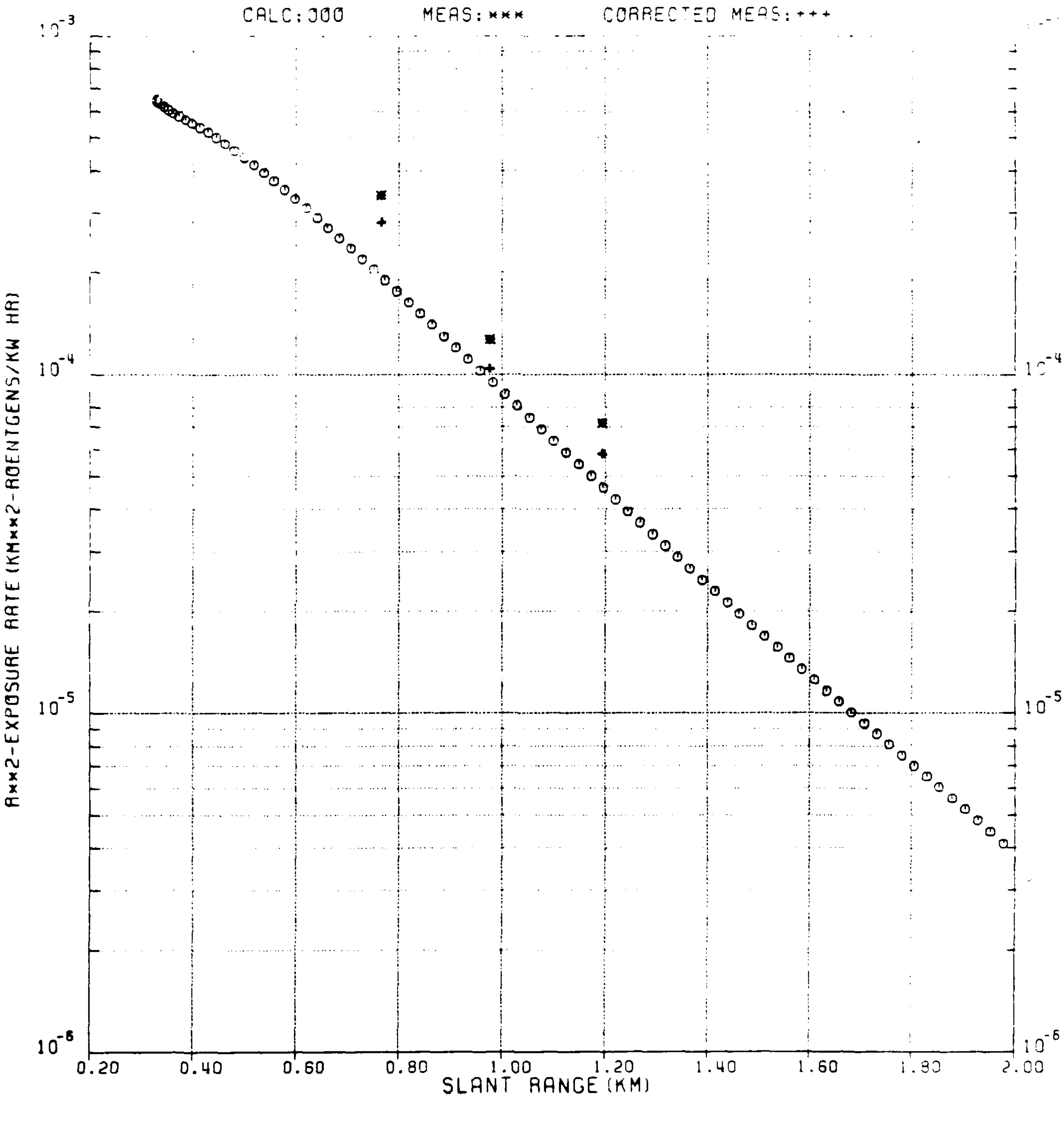


Figure 19. BREN reactor gamma ray kerma rate versus slant range measured and calculated at 15 meters.

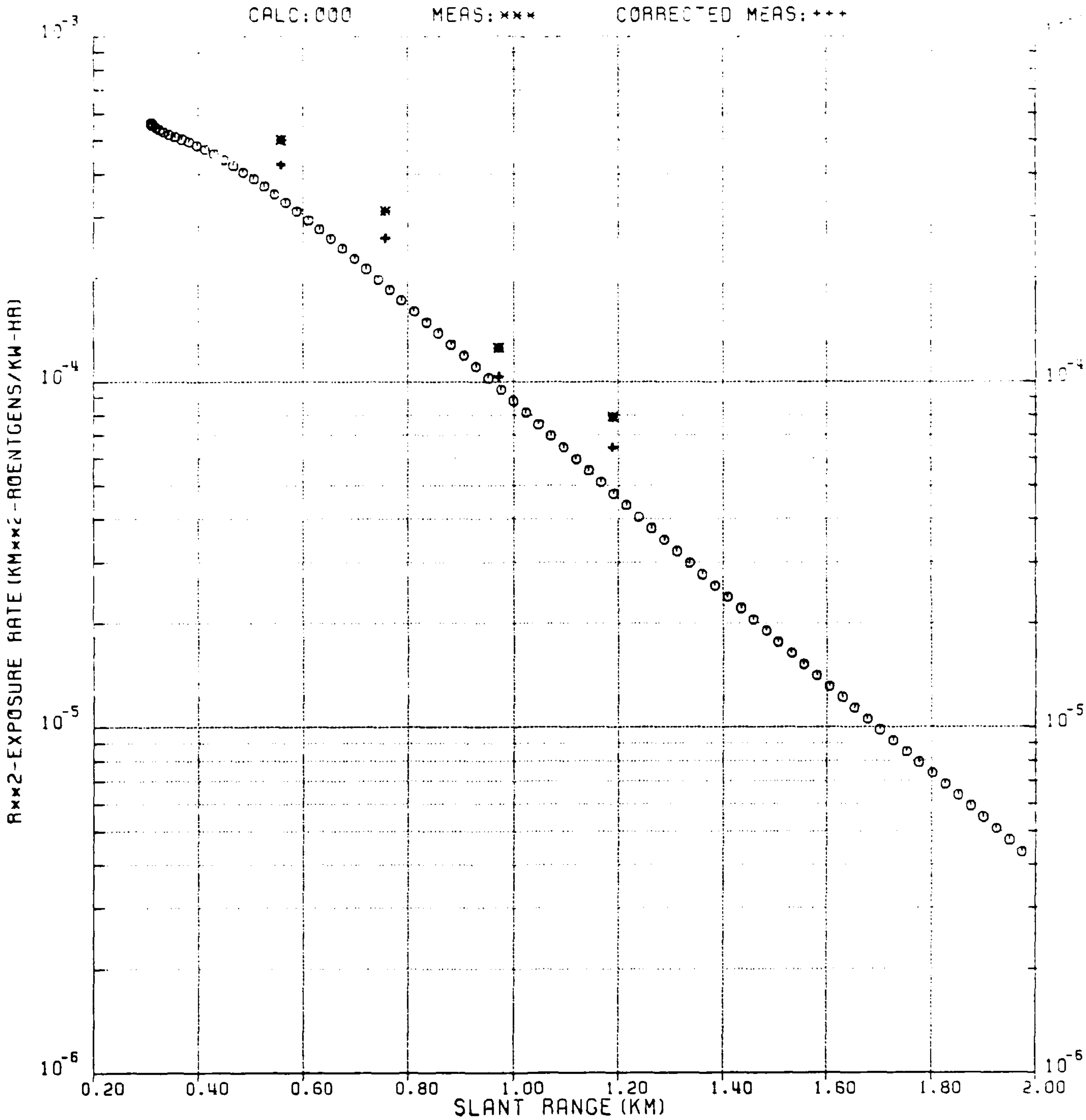


Figure 20. BREN reactor gamma ray kerma rate versus slant range measured and calculated at 30 meters.

Therefore, it was decided to further expand the quadrature to 240 angles. Although such a quadrature set is normally referred to as S_{20}, the set used was in fact an S_8 expanded 5 for 1 in the polar dimension. The results for neutron transport in the modified quadrature set and for gamma ray transport using all three quadrature sets are shown in Figures 7 and 8, respectively, as represented by free-in-air dose isocontours. The reduction in gamma ray transport ray effects obtained by increasing the order of quadrature is readily apparent. Contours for the 240 angle calculation are slightly off set from the others due to interim modifications in soil and air constituents. Reported transport results for neutrons and gamma rays, as well as the elemental constituent data in Table 1 are consistent with the final choice of problem composition and quadrature size.

Neutron and gamma ray dosimetry values were obtained for comparison to measured quantities using a four element (Caswell) tissue kerma for neutrons[19] (adjusted for the 170 KeV energy cutoff value of the RADSAN proton recoil counter) and air ionization (roentgen) response[11] for gamma rays. These response functions are listed in Table 4. Figures 9 through 14 show the calculated and measured[10] neutron doses (free-in-air) for the different detector heights in terms of R^2-dose versus range. The measured and calculated neutron doses compare very favorably at ground level. At the other detector heights the calculations are higher than the measurements by some 10 to 30%. Although the calculations are consistently higher than the measured values there is no identifiable trend to the size of the discrepancy in relation to detector height. However, it is possible that the increased measurement relative to the calculation at ground level reflects a ground-detector interaction or a source angularity which was not accounted for in these calculations. In any event, some inconsistencies are to be expected, since the measurements represent a composite of values taken at various times and meteorological conditions and scaled to a common total air density, which corresponds to that used in the calculation.

The gamma radiation exposures measured[10] and calculated for the BREN reactor are shown in Figures 15 through 20 for various detector heights. The measurements were performed with the same neutron insensitive G-M tubes (PHIL

meters) as used in the Co-60 measurements. The calibration of these counters involved establishing a detector response plateau to a known Co-60 source intensity and obtaining a relationship to convert the observed count rate to exposure rate. The failure to calibrate the G-M system for the incident gamma rays sufficiently energetic to produce pair production in the detector would then be interpreted as additional gamma rays. To correct for the enhanced detector response and the resulting increase in the count rate due to energetic gamma rays a factor was derived and applied to the measured data before comparing them to the calculations. Numerical values for counts/gamma-fluence as a function of incident gamma energy for the PHIL G.M. tubes were taken from Figure 1 of reference 20. These numbers appear in Table 5 along with values of exposure response functions, R/gamma-fluence, and the ratios of the two yielding counts/R. The latter quantities have been normalized to the corresponding value at the Co-6o energy (1. - 1.5 MeV group) from where the count rate stays constant down to about .45 MeV. The detector response below this energy begins to diminish due to the lead and tin shielding material encasing the counter.[21] Values of counts/R versus energy below .45 MeV relative to the constant response were taken from Figure 2 of Reference 21, and appear in Table 5. The correction to the measured exposure rate was then applied according to:

$$\frac{\int dE\ D(E)*\left[\frac{\text{counts}}{R}\right] @\ 1.25\ \text{MeV}}{\int dE\ D(E)*\left[\frac{\text{counts}}{R}\right](E)} * R(\text{measured})$$

where D(E) represents the calculated energy differential exposure rate and $\left(\frac{\text{counts}}{R}\right)(E)$ is the energy dependent detector response per unit exposure normalized such that counts/R (1.25 MeV) = 1. The integration is carried out over all detector energies. Table 6 lists these correction factors for each detector location along with the reported measurements. The measured data in Figures 15 through 20 correspond to the corrected values as outlined above. The measurements show some scatter relative to the calculations but are generally higher by between 25 and 50%. Qualitatively, this discrepancy is consistent with that recorded by Straker.[22] However, agreement of the gamma ray relaxation length between the measured values and current calculations is much better than that shown in the earlier report.

Table 5. PHIL detector response correction factors in the DLC-31, 21 gamma ray group structure

Group No.	Upper Energy (MeV)	R/ fluence	Counts / fluence	Counts/R	Normalized Counts/R
1	14.0	3.102-9	2.06-5	6.63+3	1.71
2	10.0	2.454-9	1.55-5	6.31+3	1.63
3	8.0	2.117-9	1.30-5	6.12+3	1.58
4	7.0	1.948-9	1.13-5	5.78+3	1.49
5	6.0	1.711-9	9.57-6	5.59+3	1.44
6	5.0	1.490-9	7.88-6	5.29+3	1.36
7	4.0	1.257-9	6.18-6	4.92+3	1.27
8	3.0	1.068-9	4.91-6	4.60+3	1.19
9	2.5	9.308-10	4.07-6	4.37+3	1.13
10	2.0	7.834-10	3.22-6	4.11+3	1.06
11	1.5	6.115-10	2.37-6	3.88+3	1.00
12	1.0	4.462-10	1.70-6	3.80+3	9.80-1
13	7.0-1	3.132-10	1.23-6	3.93+3	1.01
14	4.5-1				1.06
15	3.0-1				1.06
16	1.5-1				7.90-1
17	1.0-1				5.30-1
18	7.0-2				0
19	4.5-2				0
20	3.0-2				0
21	2.0-2				0

Table 6. PHIL detector gamma exposure rate correction factors as a function of the detector location

GR = 457 meters

Detector Height (m)	Meas. Exp. Rate (R/Kwh)	Correction Factor	Corrected Measurement
0.15	1.954-3	.837	1.635-3
0.90	-	-	-
1.8	1.858-3	.838	1.557-3
5.6	1.796-3	.839	1.507-3
14.0	-	-	-
33.0	1.609-3	.849	1.366-3

Gr = 671 meters

Detector Height (m)	Meas. Exp. Rate (R/Kwh)	Correction Factor	Corrected Measurement
0.15	6.450-4	.828	5.341-4
0.90	6.144-4	.829	5.093-4
1.8	5.763-4	.829	4.778-4
5.6	-	-	-
14.0	-	-	-
33.0	-	-	-

GR = 686 m

Detector Height (m)	Meas. Exp. Rate (R/Kwh)	Correction Factor	Corrected Measurement
0.15	5.561-4	.828	4.605-4
0.90	5.810-4	.829	4.816-4
1.8	5.980-4	.829	4.957-4
5.6	6.040-4	.830	5.013-4
14.0	5.790-4	.832	4.817-4
33.0	5.440-4	.836	4.548-4

GR = 915m

Detector Height (m)	Meas. Exp. Rate (R/Kwh)	Correction Factor	Corrected Measurement
0.15	1.546-4	.818	1.265-4
0.90	1.724-4	.819	1.412-4
1.8	1.198-4	.819	9.812-5
5.6	1.323-4	.820	1.085-4
14.0	1.332-4	.820	1.092-4
33.0	1.331-4	.824	1.097-4

GR = 1143m

Detector Height (m)	Meas. Exp. Rate (R/Kwh)	Correction Factor	Corrected Measurement
0.15	5.622-5	.808	4.543-5
0.90	5.366-5	.809	4.341-5
1.8	5.074-5	.809	4.105-5
5.6	4.835-5	.810	3.916-5
14.0	5.025-5	.812	4.080-5
33.0	5.595-5	.814	4.554-5

GR = 1372m

Detector Height (m)	Meas. Exp. Rate (R/Kwh)	Correction Factor	Corrected Measurement
0.15	2.200-5	.797	1.753-5
0.90	-	-	-
1.8	2.341-5	.798	1.868-5
5.6	2.033-5	.800	1.626-5
14.0	-	-	-
33.0	-	-	-

Possible sources of the BREN reactor gamma ray discrepancy were investigated by reviewing both the measurement documentation and the calculation input parameters. The presence of the fission product gamma ray component in the calculated source was confirmed by ORNL.[23] However, this could not be absolutely verified because records of the original calculations had been lost. A number of one dimensional slab geometry transport calculations were performed to determine the effect of moisture uncertainties in the ground. However, these showed that only 10 to 20% increases in gamma ray exposure could be obtained as a result of increases in soil moisture content within a credible range about those reported. It is possible that some trace elements, omitted from the analytical soil composition for lack of cross section data, could be the source of the discrepancy. It is also possible that the PHIL detector readings were contaminated by thermal neutrons, although efforts had been made to prevent this through the use of Li-6 shields about the detector. Preliminary analyses have shown that such contamination (of the order of $2\text{-}5*10^9$ thermal neutrons/cm^2) could completely resolve the observed discrepancies. Having exhausted all the likely possibilities for the source of the gamma ray measurement-calculation discrepancy without definitively resolving the problem, it was decided to attempt a second comparison of analytical and experimental data on a similar but separate system, APR, in an attempt to resolve the issue by independent means.

SECTION 3

APR CALCULATIONS

The APR facility is located at the Aberdeen Proving Ground, Maryland. The reactor is very similar to HPRR as mentioned previously. The total neutron leakage from the device, as inferred from reactor midline plutonium foil and polar sulphur foil measurements, is 1.1×10^{17} n per kWh. The neutron leakage spectra for the device is taken to be that calculated by LANL, as shown previously in Table 3 of this report. The gamma leakage spectra, also shown in Table 3, was calculated by ORNL and is normalized on the basis of 0.65 gamma rays per neutron. The APR reactor has a maximum elevation of 14 meters. The land around the reactor site is moderately flat and barren to approximately 200 meters, beyond which point the land is forested. A 20 meter wide corridor in the forest is used for free field measurements at ranges from 200 to 400 meters. Measurements at 1080 meters are taken on a small hill, such that the detector is approximately 13 meters above the reactor midplane, with the reactor just visible above the intervening trees.

Measurements were performed by three organizations, representing the US (APRD), Canada (DREO) and FRG (WWD). Various instruments were used in the measurements, including NE213 scintilation counters capable of spectral analysis of both neutrons and gamma rays, proton recoil devices, Bonner spheres, BF_3 counters, tissue-equivalent ionization chambers and G-M tubes. The atmospheric and surface conditions varied for each measurement period. The WWD measurements[24] were made in March 1978 with water-saturated ground. Some of the APRD measurements[24] were made in May-June 1978 with a ground containing much less moisture than the March soil. Both APRD[25] and DREO[26,27] made measurements in the falls of 1980 and 1981 at a time of much diminished soil moisture content. The average conditions for the various measurement periods are shown in Table 7.

The conditions listed for the March 1978 measurements differ from those actually used in the calculation for that period. The reason for the difference is that the calculation was part of an earlier series which used a single atmosphere for all three measurement periods, as well as an earlier measured ground composition. However, since the radiation field measurements

Table 7. Air and soil constituents for APR calculations number density (atoms/barn-cm)

Medium	Element	March 78*	March 78	May/June 78	Oct/Nov 80/81
Air	H	5.972-7	3.402-7	1.943-7	4.983-7
	N	3.999-5	4.149-5	4.025-5	3.992-5
	O	1.152-5	1.181-5	1.139-5	1.145-5
air (g/cc)		1.237-3	1.279-3	1.239-3	1.23-3
Soil	H	4.05-2	3.89-2	2.14-2	1.49-2
	C	1.53-3	1.25-3	1.55-3	1.66-3
	N	0	3.95-5	4.83-5	5.19-5
	O	3.95-2	4.06-32	3.67-2	3.53-2
	Na	1.80-4	1.20-4	1.47-4	1.57-4
	Mg	2.80-4	7.58-5	9.27-5	1.00-4
	Al	3.00-4	1.14-3	1.41-3	1.51-3
	Si	9.30-3	7.95-3	9.84-3	1.06-2
	S	9.00-6	2.94-6	3.51-6	3.83-6
	Cl	1.00-6	2.83-6	3.47-6	3.76-6
	K	5.30-4	1.70-4	2.10-4	2.25-4
	Ca	1.80-3	9.63-4	1.19-3	1.28-3
	Mn	1.00-4	5.96-6	7.46-6	8.01-6
	Fe	9.70-5	2.66-4	3.28-4	3.52-4
	Cu	1.60-6	4.03-7	5.00-7	5.32-7
soil (g/cc):		1.7	1.7	1.7	1.7

*Actual values used in the March 78 calculation, which predates the availability of improved elemental analysis performed for DREO.

made at that time extended to only 300 meters and because the soil was similar to that used currently it was decided not to recalculate that data with the updated conditions.

The balance of the soil constituents shown in Table 7 were taken from an analysis performed for DREO.[28] The results of that analysis were modified to include additional silicon, as recommended by DREO. Further, additional $CaCO_3$ was added to account for discrepancies in the assigned weight percent and to bring the DREO measurement more in line with those performed previously. Finally no soil moisture content was reported for the fall measurement periods. Therefore, a 12.9% by weight water content was chosen based on the intensity of hydrogen capture gamma ray lines measured in experiments during those periods. The APR reactor calculations were carried out using a point source, characterized by the LANL neutron source spectrum, at a height of 14 meters above the ground. The calculation geometry for the March 1978 period extended to 1500 meters radially and 1000 m axially, made up of 73 and 81 meshes, respectively. One meter of soil material was included. The calculations for the summer 1978 and fall 1980/1981 periods were performed with geometries extending to 1900 meters radially and 1000 meters axially, made up of 89 and 81 meshes, respectively. These also included one meter of soil. No albedos were used in these calculations in order to minimize their cost and owing to the fact that the source height was very low.

The computations were performed using the same library of cross sections as used in the BREN calculations, the 37 neutron, 21 gamma ray DLC-31 coupled set with P_3 Legendre angular scattering treatment. The computations likewise used the analytic first collision source treatment to produce a volume-distributed source of both neutrons and gamma rays. The computations were begun using a 48 angle (S_8) quadrature set. This treatment gave satisfactory results for neutron transport. However, the gamma ray results were plagued with very significant ray effects. Therefore, the 48 angle fluences were converted into 160 angle fluences and the problem run to convergence (gamma rays only) in the new S_{16} quadrature set. The results for the two quadrature sets are shown as free-in-air dose isocontours in Figures 21 and 22 for neutrons and gamma rays respectively. It can be seen that substantial gamma ray streaming along quadrature lines takes place in the S_8 results, due

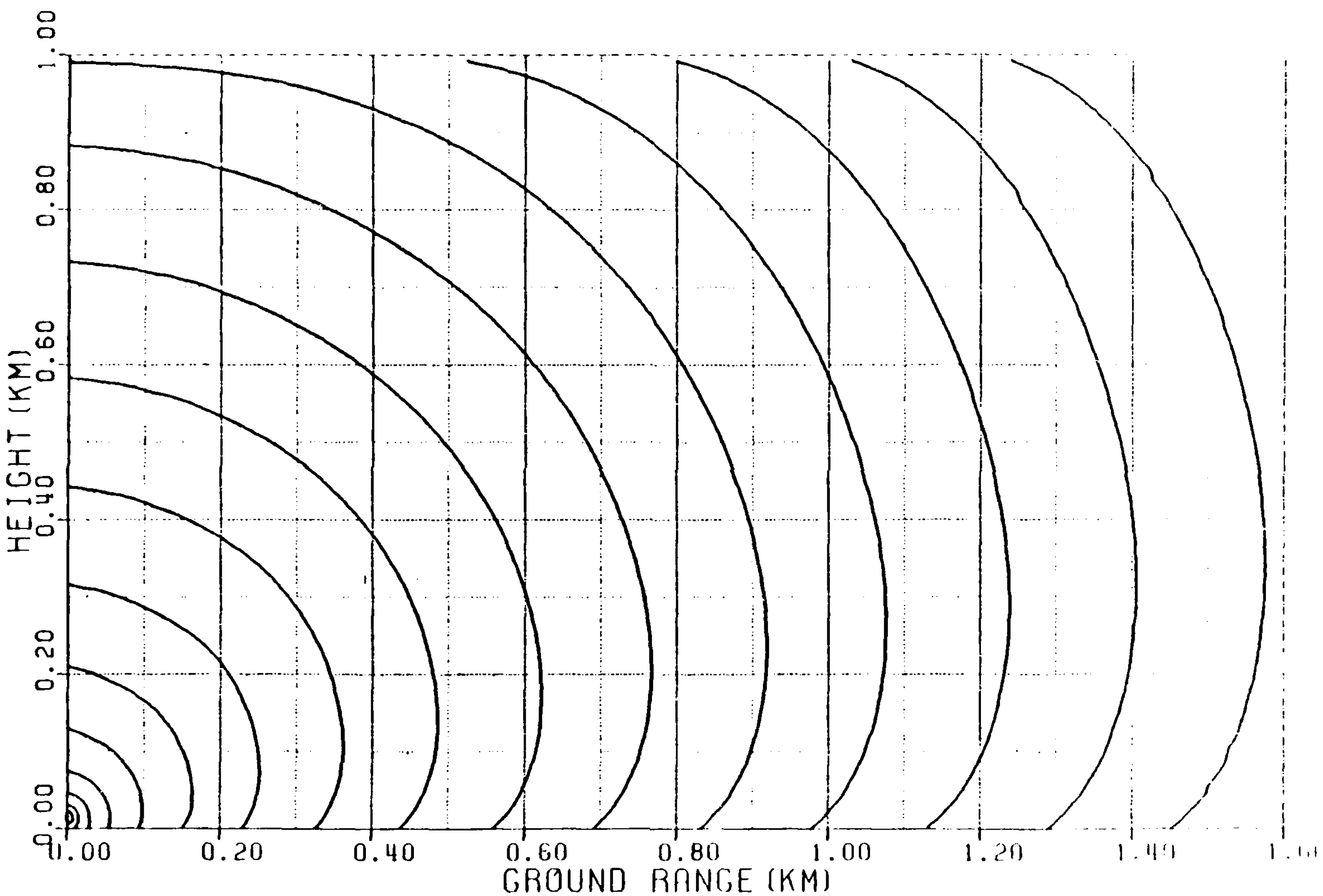


Figure 21. APR reactor calculated neutron kerma rate isocontours.

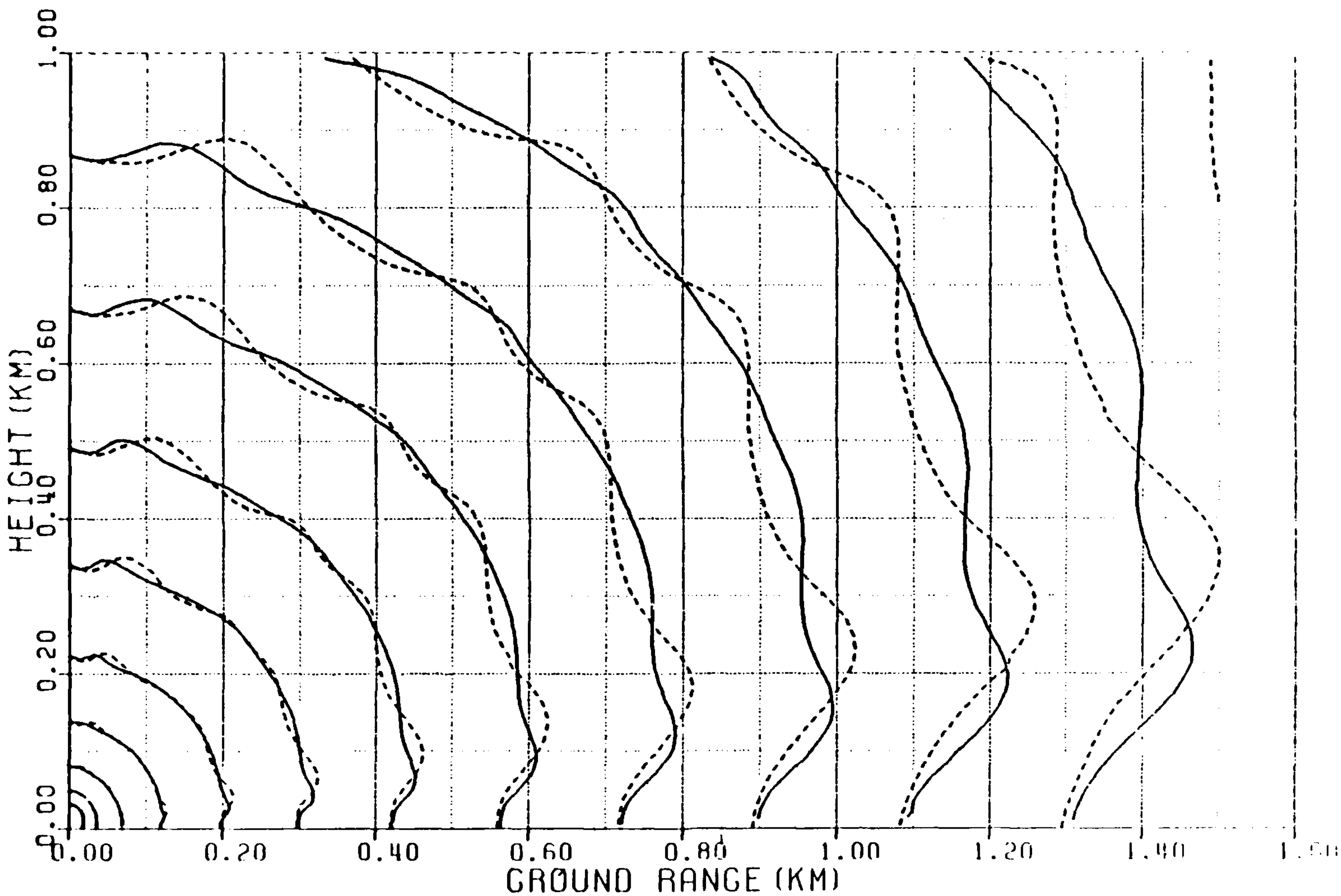


Figure 22. APR reactor calculated gamma ray kerma rate isocontours for 48 to 160 angle quadratures.

primarily to gamma rays produced in the ground below the reactor. Conversion to S_{16} quadrature helps reduce the ray effect problem but does not eliminate it. The later calculations for the summer and fall measurement periods were performed using a 240 angle, modified (S_8) quadrature set for the gamma rays. These calculations were performed by first converging the neutron transport in S_8 quadrature in the absence of gamma rays. The 48 angle neutron fluences were then converted to 240 angles and were used to restart the computations in which the gamma rays were included and run to convergence. Again, no attempt was made to converge the neutron in the 240 angle quadrature. A comparison of typical gamma ray transport results using the 240 angle set with those obtained using the 160 angle set may be made from the isodose contours provided in Figure 23. As can be seen, the 240 angle set is virtually free of quadrature streaming with the exception of a small perturbation near the ground surface, where the largest polar angle step occurs in the quadrature.

The measured data are available for comparison to the calculations in two modes. The first is integral and includes free-in-air dosimetry calibrated in rads(tis) measured with various dosimeters, as well as response matrices folded with NE213 measured fluence spectra. The second mode is differential and involves the use of fluence energy spectra which are available for both neutrons and gamma rays. It has been the experience of SAIC that comparison of calculated and measured quantities on the basis of integral quantities alone can mask inconsistencies which may be important under even slightly altered circumstances. Therefore, since the transport problems posed by the devices detonated over Japan represent a considerably altered circumstance from that of APR, comparisons have been made in both the integral and energy-differential modes.

Comparison of calculated and measured kerma values at APR was complicated by the fact that measurements were calibrated against two different types of kerma. First, all the dosimeters which recorded kerma directly, ionization chambers and G-M tubes, were calibrated by the National Bureau of Standards. This was taken to mean that the reference kerma reflected a four element composition for soft tissue taken from Caswell[19], as follows: 10.2%H, 12.3%C, 3.5%N, and 74%O. Energy-differential kerma factors for neutrons and gamma rays corresponding to this tissue composition are given in Table 8. The

Table 8. Fluence-to-kerma factors for four element (Caswell) tissue in the DLC-31, 37 neutron-21 gamma ray, group structure

Group No.	Upper Energy (MeV)	Neutron kerma (rad/fluence)	Group No.	Upper Energy (MeV)	Gamma Ray kerma (rad/fluence)
1	19.64	7.59-9*	1	14.0	2.96-9
2	16.90	7.16-9	2	10.0	2.34-9
3	14.92	6.87-9	3	8.0	2.03-9
4	14.19	6.74-9	4	7.0	1.84-9
5	13.84	6.52-9	5	6.0	1.64-9
6	12.84	6.24-9	6	5.0	1.43-9
7	12.21	6.16-9	7	4.0	1.21-9
8	11.05	5.78-9	8	3.0	1.03-9
9	10.0	5.53-9	9	2.5	8.98-10
10	9.048	5.27-9	10	2.0	7.54-10
11	8.187	5.11-9	11	1.5	5.87-10
12	7.408	4.95-9	12	1.0	4.29-10
13	6.376	4.62-9	13	7.0-1	3.00-10
14	4.965	4.39-9	14	4.5-1	1.94-10
15	4.724	4.31-9	15	3.0-1	1.09-10
16	4.066	4.07-9	16	1.5-1	5.23-11
17	3.012	3.44-9	17	1.0-1	3.47-11
18	2.384	3.15-9	18	7.0-2	2.91-11
19	2.307	3.11-9	19	4.5-2	4.34-11
20	1.827	2.69-9	20	3.0-2	9.45-11
21	1.108	2.05-9	21	2.0-2	3.19-10
22	.5502	1.27-9			
23	.1576	7.81-10			
24	.1111	5.44-10			
25	5.248-2	3.07-10			
26	2.479-3	2.09-10			
27	2.188-2	1.43-10			
28	1.033-2	6.11-11			
29	3.355-3	2.16-11			
30	1.234-3	9.02-12			
31	5.829-4	3.11-12			
32	1.013-4	1.21-12			
33	2.902-5	1.26-12			
34	1.068-5	1.95-12			
35	3.059-6	3.31-12			
36	1.125-6	5.44-12			
37	4.140-7	2.24-11			

*Read as 7.59×10^{-9}.

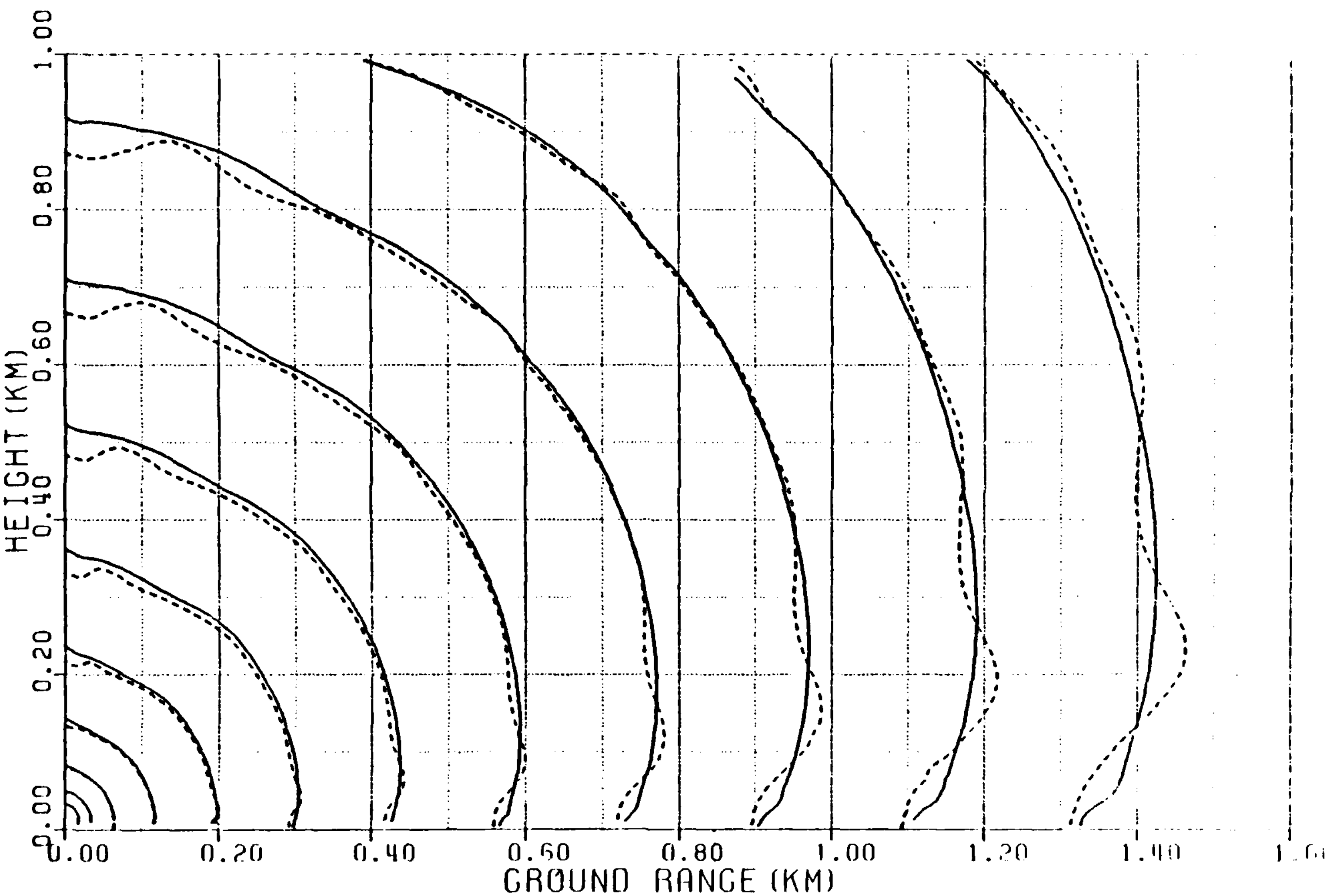


Figure 23. APR reactor calculated gamma ray kerma rate isocontours for 160 to 240 angle *quadratures*.

reported kerma values were produced by folding the energy-differential kerma factors from DLC-31 with measured spectra. The DLC-31 kerma were generated for an eleven element homogeneous reference man composition. SAIC has compared the results of using the two sets of kerma in APR radiation fields and has found that the differences are small, amounting to 3% or less. Therefore, the Caswell soft tissue kerma are used throughout to represent the calculated results.

The March 1978 measurements by WWD of gamma ray kerma via NE213 - obtained spectra are presented along with the calculated values in Figure 24. The measured and calculated values are shown to be in excellent agreement. WWD neutron measurements were for a limited spectral range and are not shown here as kerma-equivalent values.

The May-June 1978 measurements by APRD of gamma ray kerma via a G-M dosimeter are presented along with the calculated values in Figure 25. The overall agreement between the two sets of data is generally comparable to that for WWD. Neutron kerma were measured by APRD by a combination of NE213 and proton recoil methods and by taking the difference between tissue equivalent ionization chamber values and G-M tube results. These two sets of neutron results are shown along with equivalent calculated values in Figure 26. The agreement is generally good to 170 meters. Beyond that the measured values decline relative to the calculated values. The IC measured total kerma shown in Figure 27 reflect the same trend relative to the calculations as do the neutron kerma.

During the falls of 1980 and 1981, measurements were made with various devices and at various ranges by APRD, DREO and WWD. Gamma kerma results are shown along with those calculated in Figure 28. Again, the agreement between measured and calculated gamma ray kerma is very good, in this instance to more than a kilometer. Neutron kerma measurements and calculations corresponding to the 1980 - 1981 fall time period are shown in Figure 29. Inside 170 meters agreement is on the order of 10%. At a kilometer it is approximately 30%. However at the 300 and 400 meter distance the discrepancy is greater than 50%, with the calculated values consistently higher than those measured. The total measured and calculated kerma for this time period are shown in Figure 30.

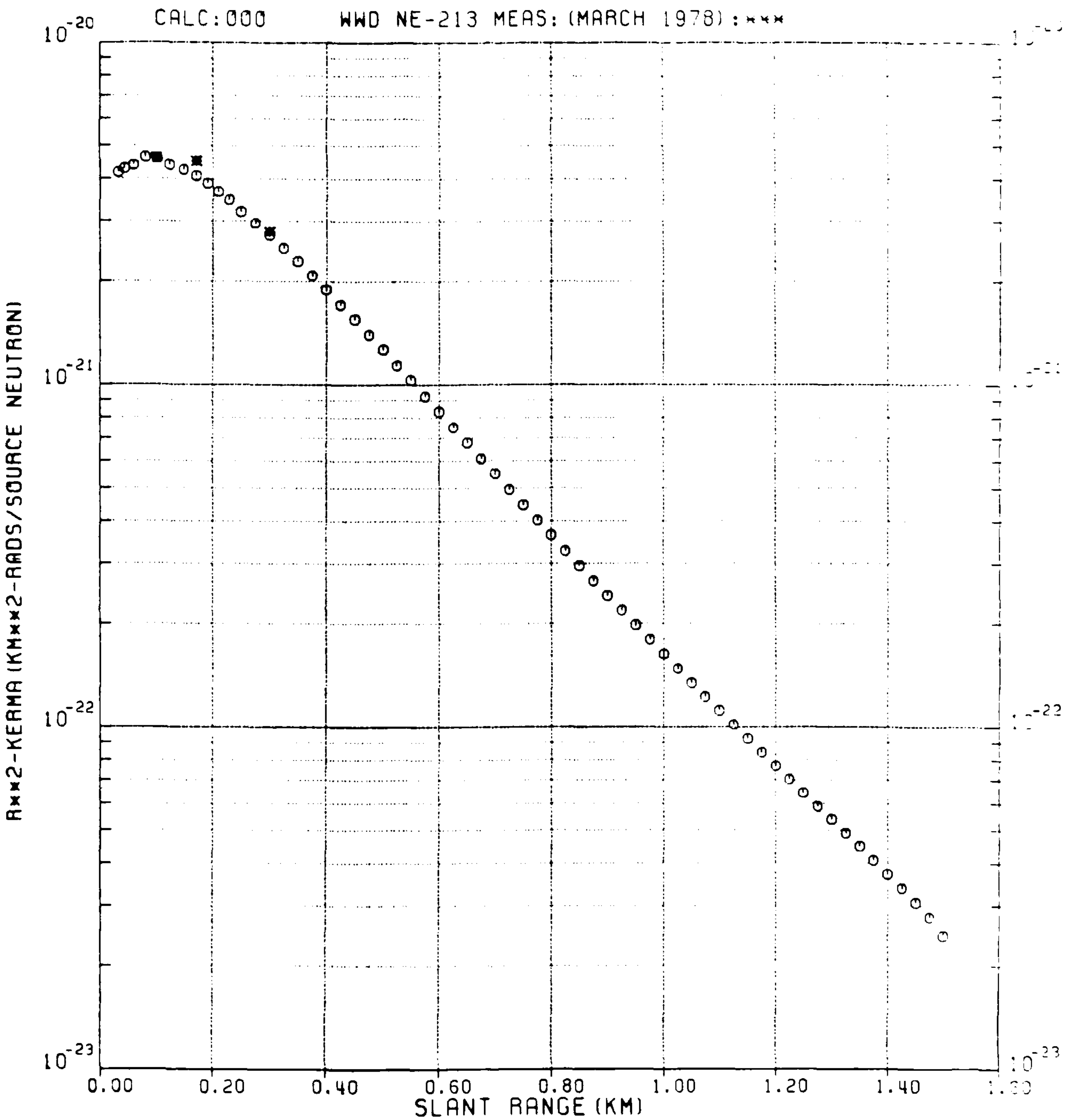


Figure 24. APR reactor gamma ray kerma calculated and measured at 1.25 meters (WWD, March 1978).

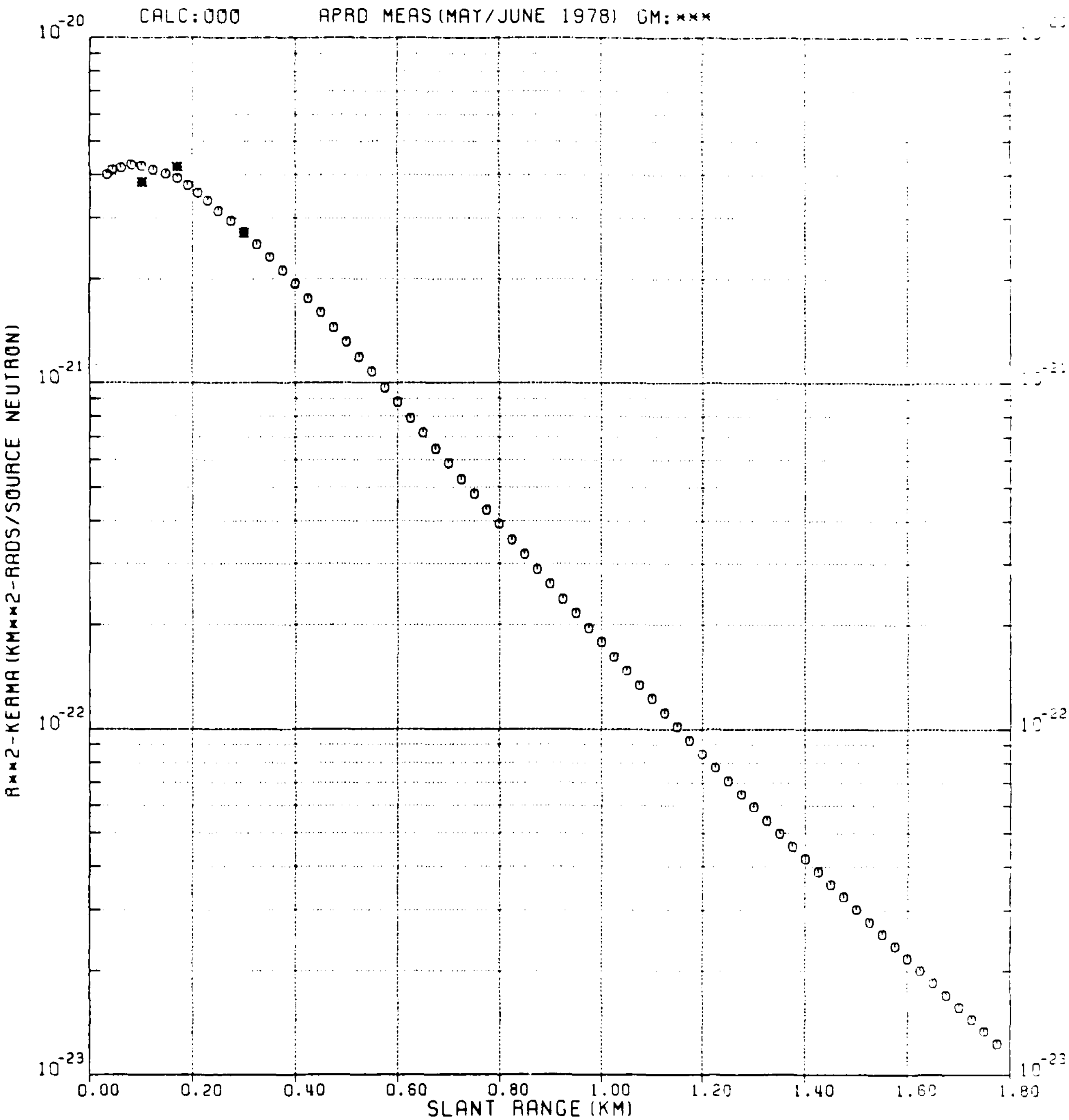


Figure 25. APR reactor gamma ray kerma calculated and measured at 1.25 meters (APRD, May/June 1978).

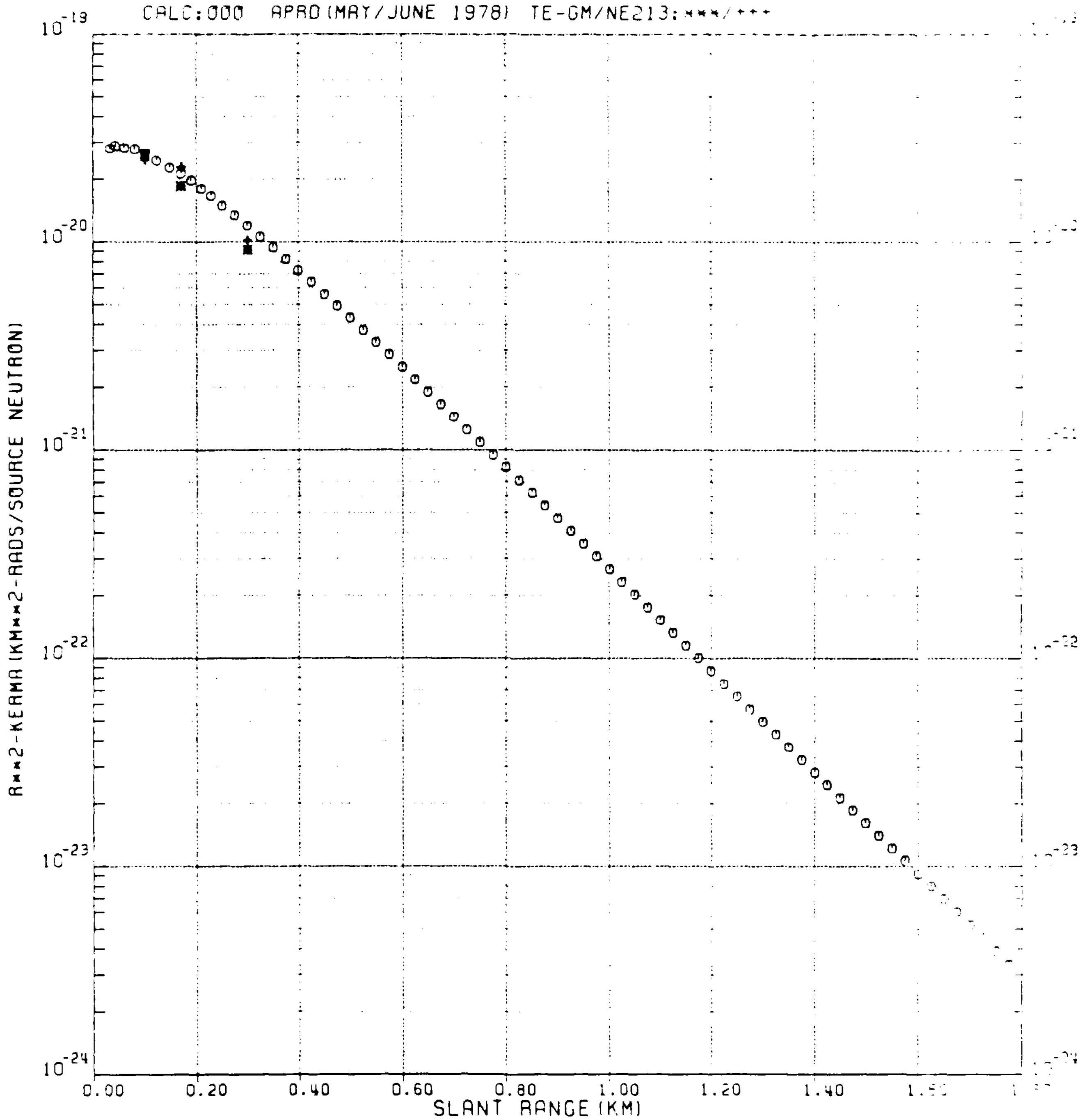


Figure 26. APR reactor neutron kerma calculated and measured at 1.25 meters (APRD, May/June 1978).

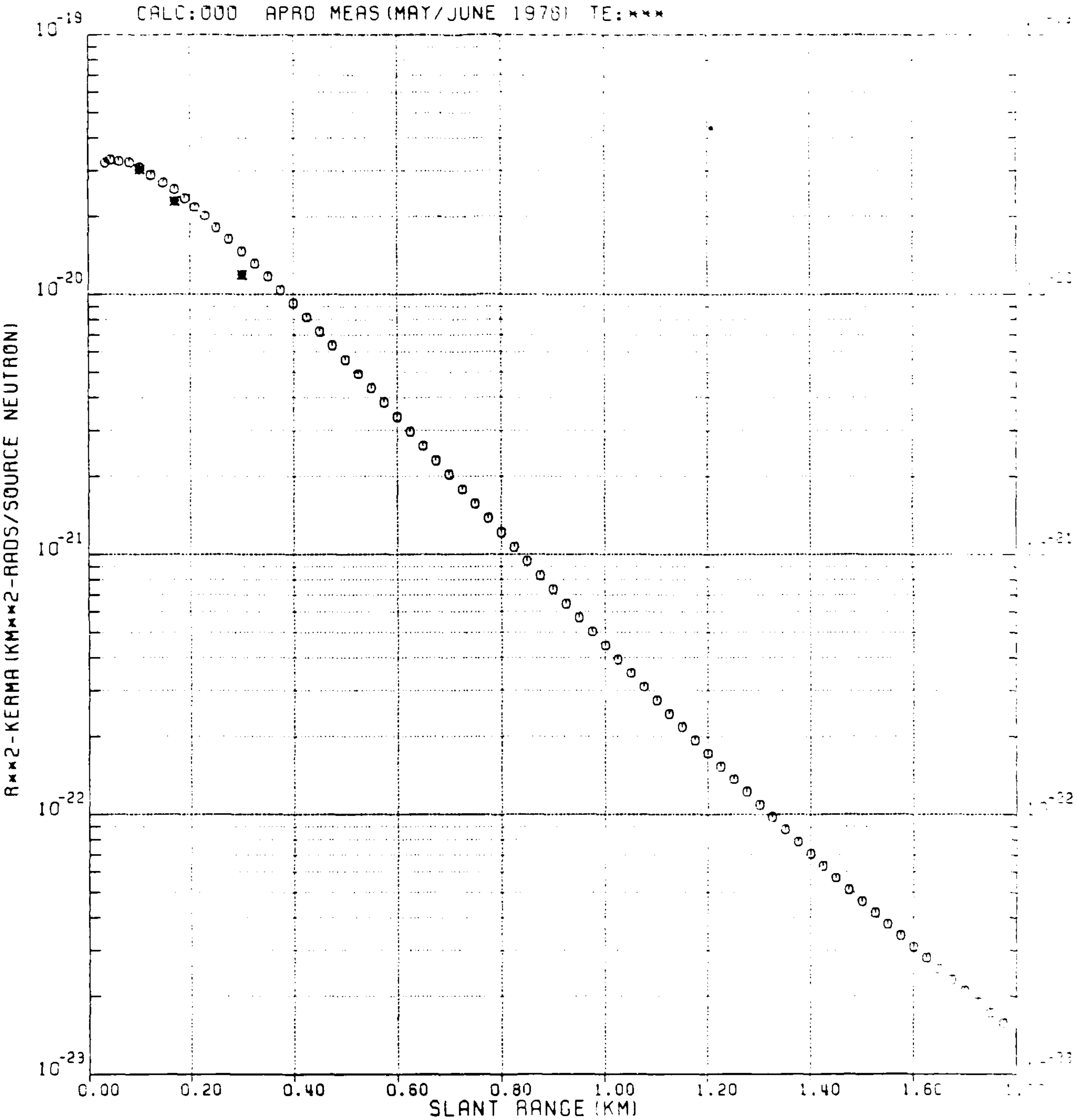


Figure 27. APR reactor total kerma calculated and measured at 1.25 meters (APRD, May/June 1978).

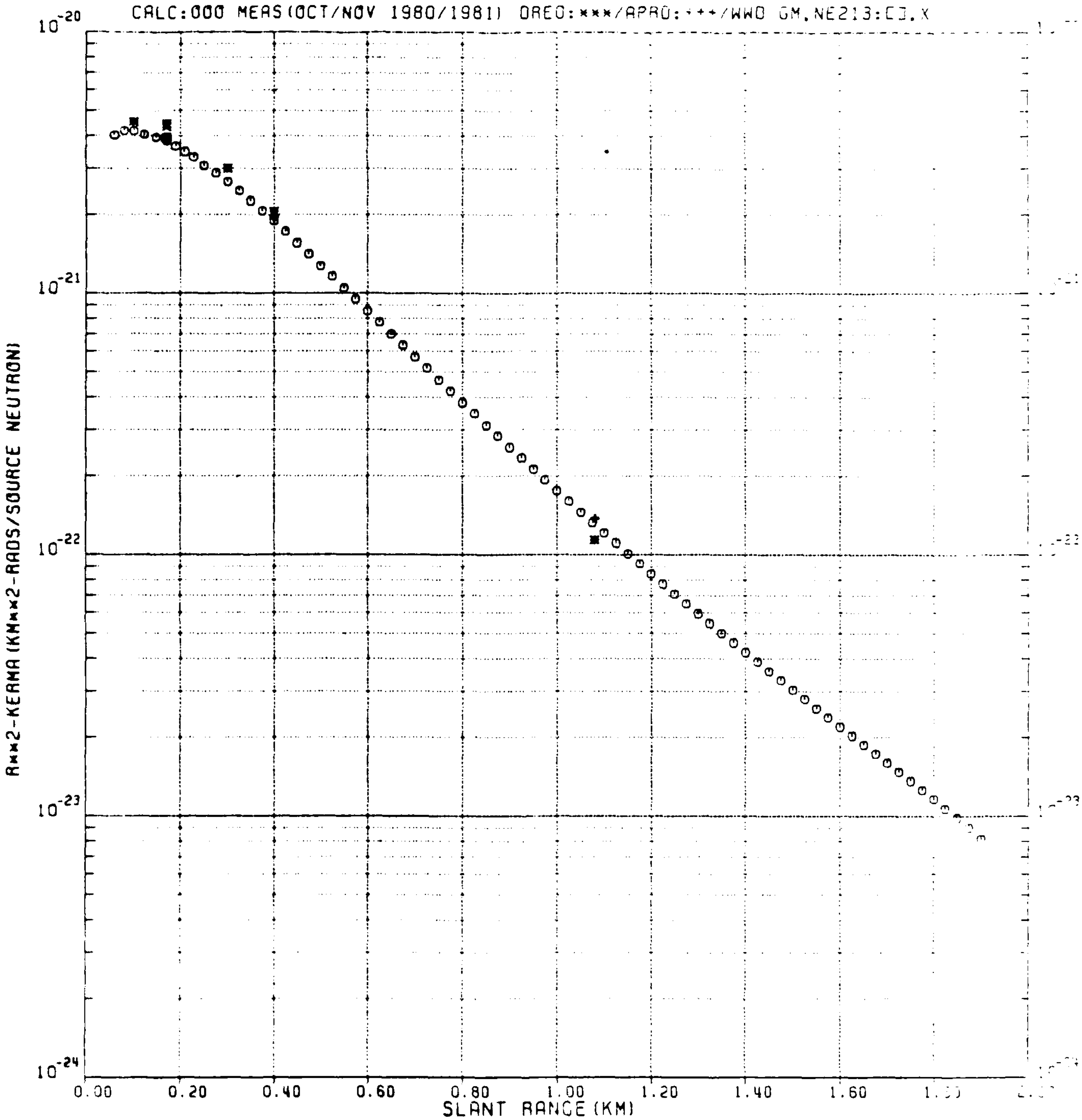


Figure 28. APR reactor gamma ray kerma calculated and measured at 1.25 meters (DREO, APRD, WWD Oct/Nov. 1980/1981).

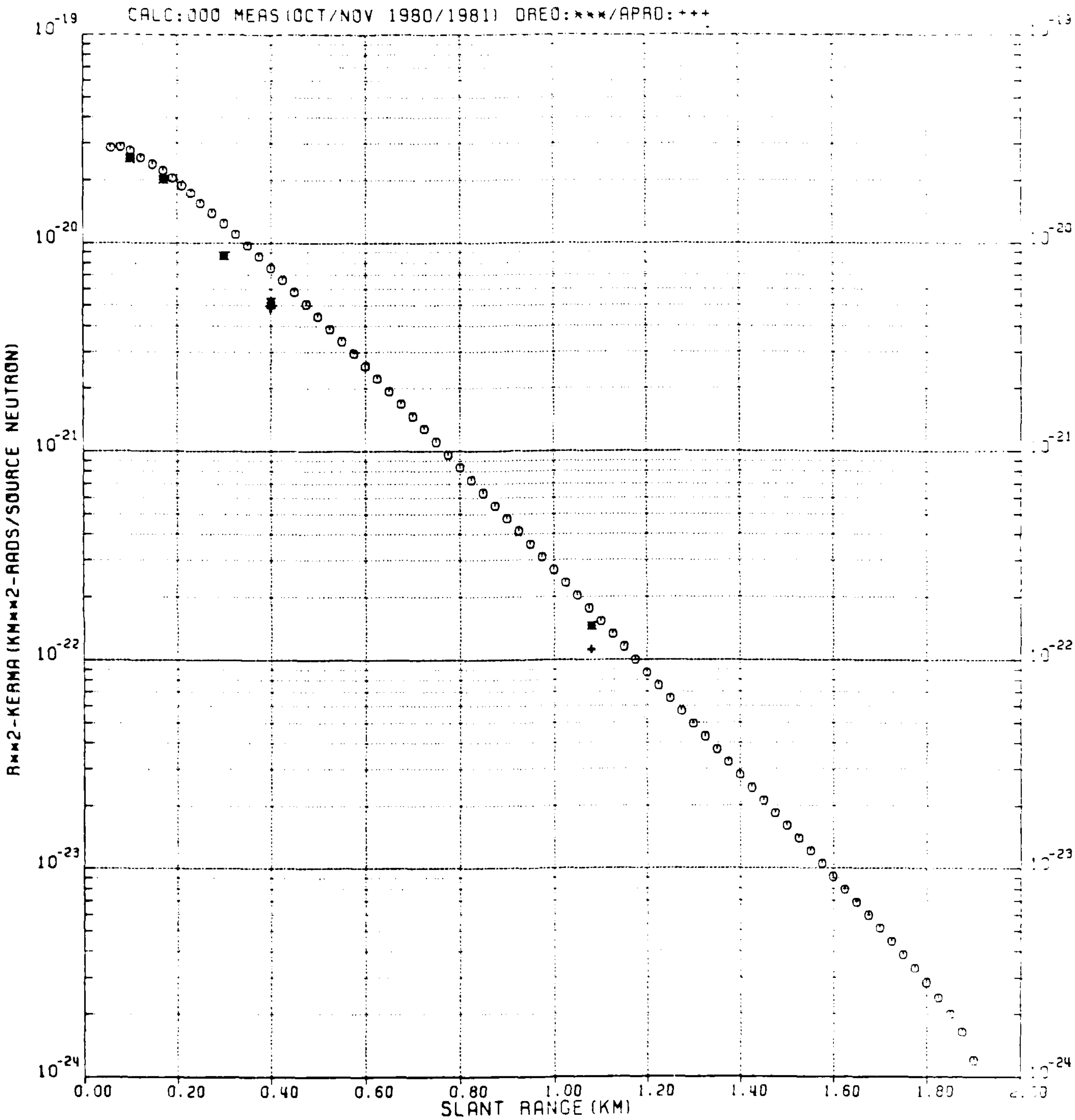


Figure 29. APR reactor neutron kerma calculated and measured at 1.25 meters (DREO, APRD Oct/Nov. 1980/1981).

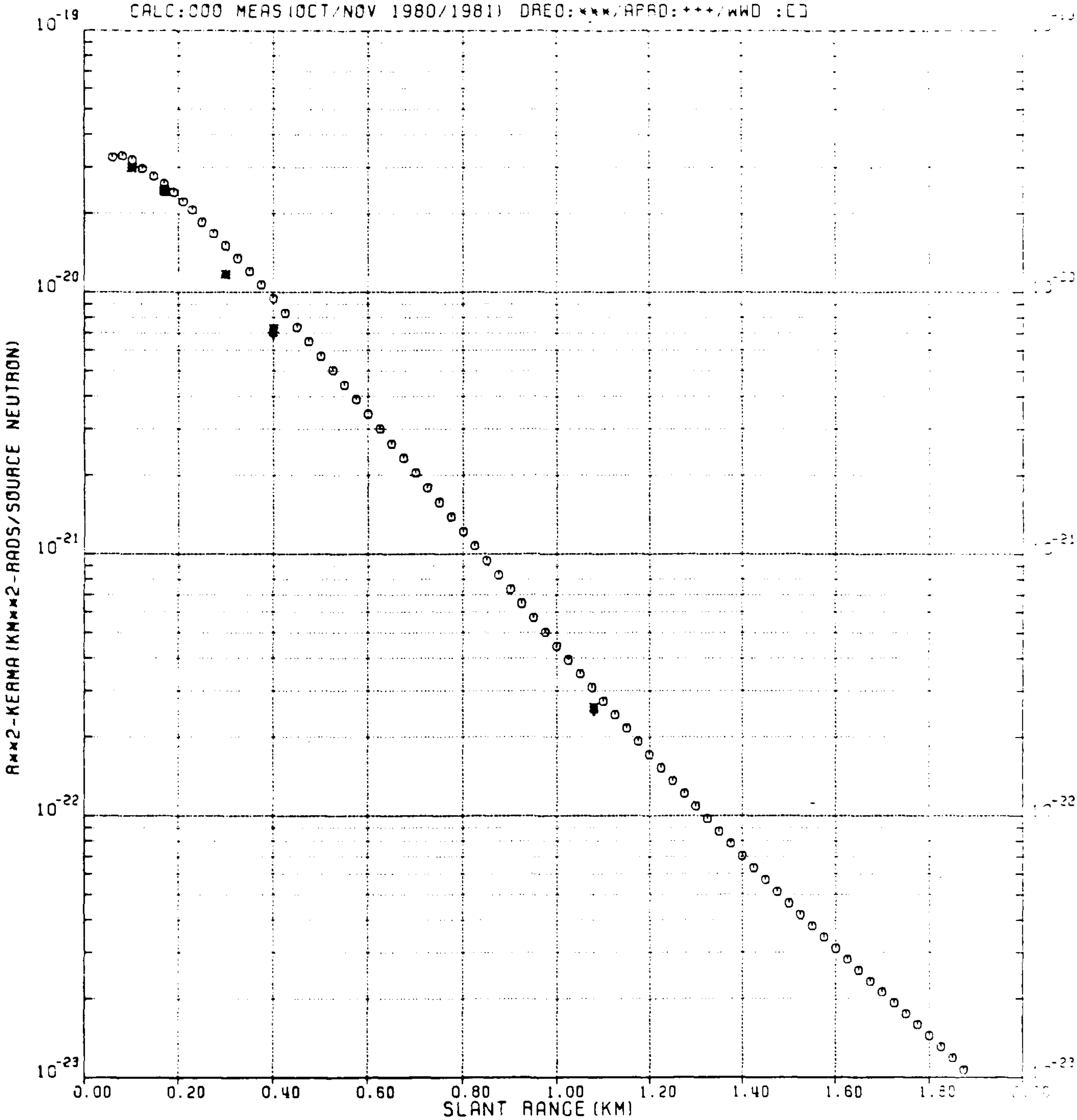


Figure 30. APR reactor total kerma calculated and measured at 1.25 meters (DREO, APRD, WWD Oct/Nov. 1980/1981).

The results are similar to those for neutrons but reflect a better measurement-calculation agreement overall with the addition of the gamma rays.

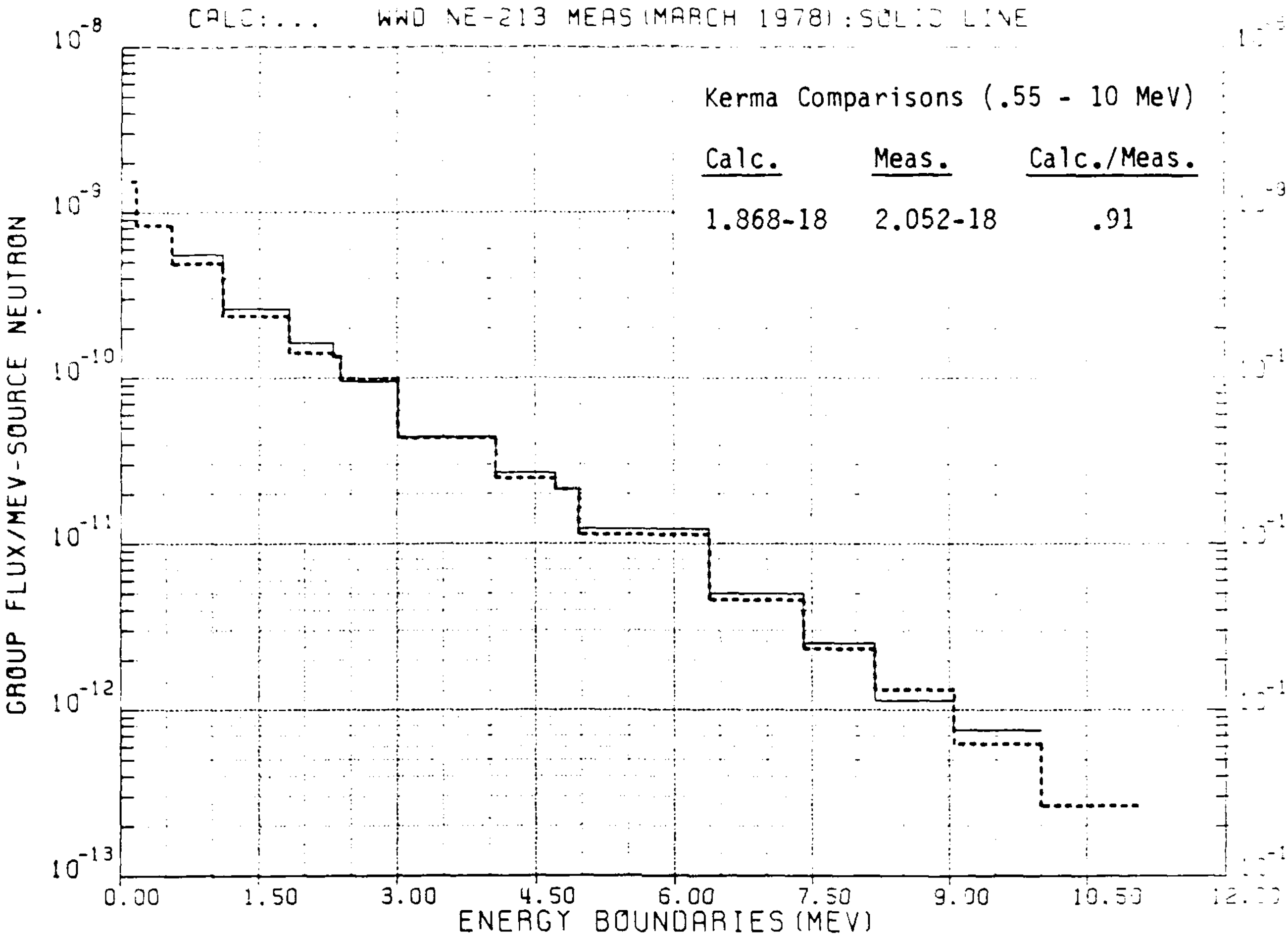
The above measurement-calculation comparisons for APRD reactor gamma rays are at odds with those made previously for BREN reactor gamma radiation. Yet, both sets of calculations were made using the same code and cross section library and similarly detailed air and ground compositions.

Thus, it seems unlikely that the BREN gamma ray measurement-calculation discrepancy was caused by some failure of the calculation methodology. It is also difficult to ascribe it to some unknown mystery element in the Nevada Test Site soil. Therefore, there is reason to suspect that the reported BREN reactor gamma ray measurement values are too high, though the cause remains speculative. However, the comparisons have raised a new set of issues, which include the general over-computation of neutron kerma, as well as the enhanced discrepancy between measured and calculated neutron kerma between 300 and 400 meters from the reactor. The nature of these discrepancies has been studied further using measured and calculated energy-differential spectra.

APR Spectral Comparisons

The first of the reported modern spectral measurements at APR were performed by the WWD group in March 1978. Their reported neutron spectra at 100, 170 and 300 meters horizontal range are presented together with calculated values in Figures 31, 32 and 33, respectively. Scalar kerma values integrated over the energy range claimed for the measurements are also provided for comparison. The results at 100 and 170 meters show a consistent measurement/calculation relationship with an overall kerma discrepancy between the two of less than 10%. The results at 300 meters reflect an 18% shift in the relationship between measured and calculated kerma. It is apparent from the calculated to measured spectra ratios shown in the Figures that this shift is due to an increase of calculated neutrons of energies less than 5 MeV relative to the measured values.

The WWD gamma ray measurements were performed using the NE213 scintillator. This device is susceptible to contamination by gamma rays produced in the detector by incident neutrons. Correction for this effect has



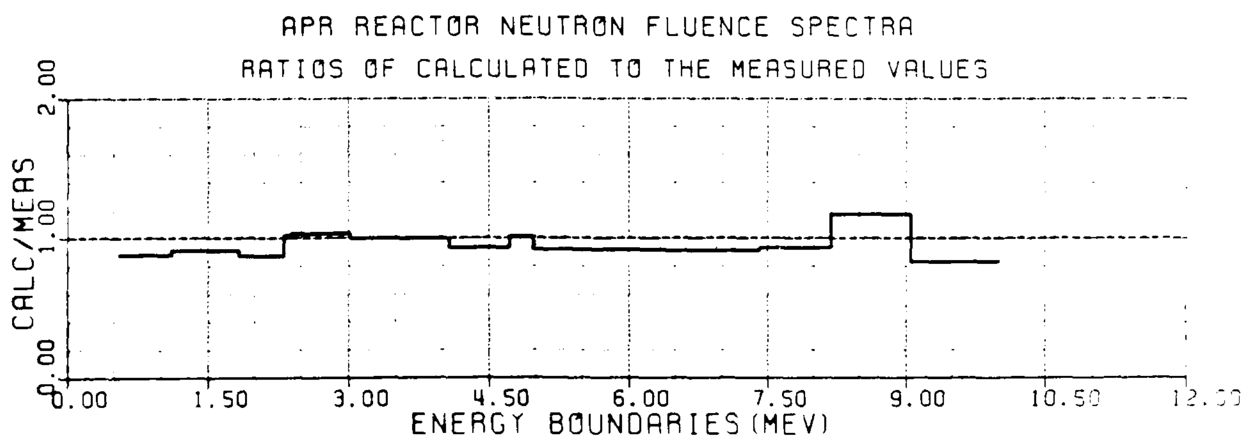


Figure 31. APR reactor neutron fluence spectra, calculated and measured at 100 meters ground range (WWD, March 1978).

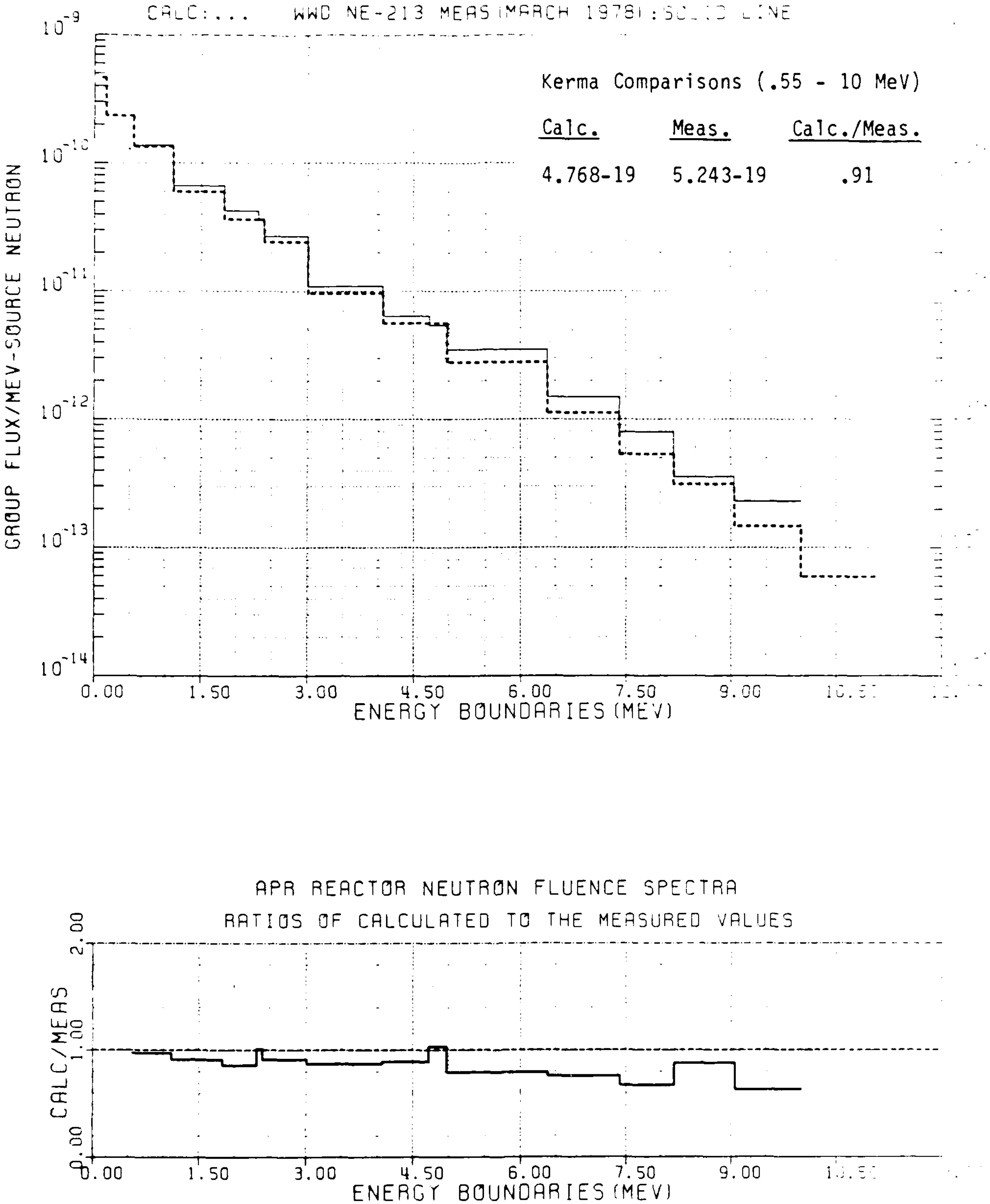


Figure 32. APR reactor neutron fluence spectra, calculated and measured at 170 meters ground range (WWD, March 1978).

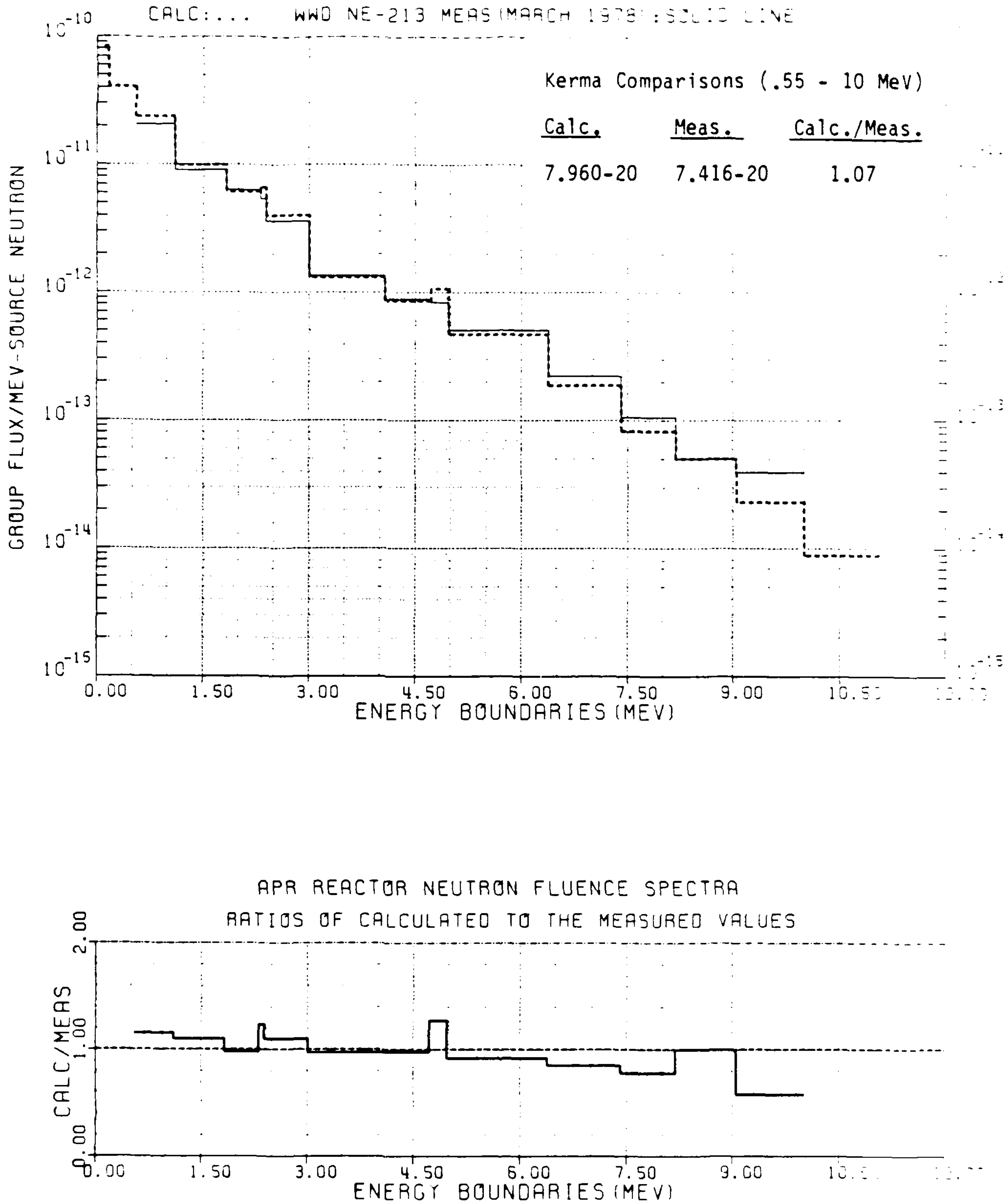


Figure 33. **APR reactor neutron fluence spectra, calculated and measured at 300 meters ground range (WWD, March 1978).**

been studied by Scott.[29] The heavy dashed lines in Figures 34, 35 and 36 depict the calculated gamma spectra, including the neutron-induced contribution. The light dashed lines depict the gamma spectra which is incident on the detector.

The effect of adding the detector contribution is particularly striking at high energies (E > 6 MeV) and in the group between 2 and 2.5 MeV, which includes the hydrogen capture gamma ray. That gamma ray is important because it provides an indication of the ground moisture content. As can be seen from the three figures, which provide gamma ray spectra as measured by WWD at 100, 170 and 300 meters, the hydrogen line is well reproduced in the calculations at all ranges only if the detector contribution is accounted for.

The kerma values in these figures and all other similar figures in this report depict the as-measured NE213 values. Thus, the detector contribution is included in the calculated values. The variation between WWD measured and calculated kerma is 11% at worst but more generally within 5%. Spectral comparisons indicate agreement within approximately $\pm$ 20% over most of the energy range, although substantial differences exist below 0.7 Mev and above 8 MeV. However, the measured values are not as reliable in these energy regions.

The APRD measurements were made slightly later in the same year as those of WWD. The calculated and measured values at the same three ranges are shown in Figures 37, 38, and 39. Comparisons between these values on the basis of kerma are every bit as good as those for WWD. The comparison of calculated and measured spectra, as depicted by the ratios of individual group values, indicates similar trends with range to those shown in the WWD comparison. However, individual group comparisons show larger discrepancies.

APRD repeated their neutron spectra measurement at 170 meters in the fall of 1980. Measured and calculated values for these spectra are given in Figure 40. The kerma comparison is within the same bound as in the case of the earlier measurement. However, individual groups above 2 MeV show much better agreement than was previously the case. The 10% disagreement between measured

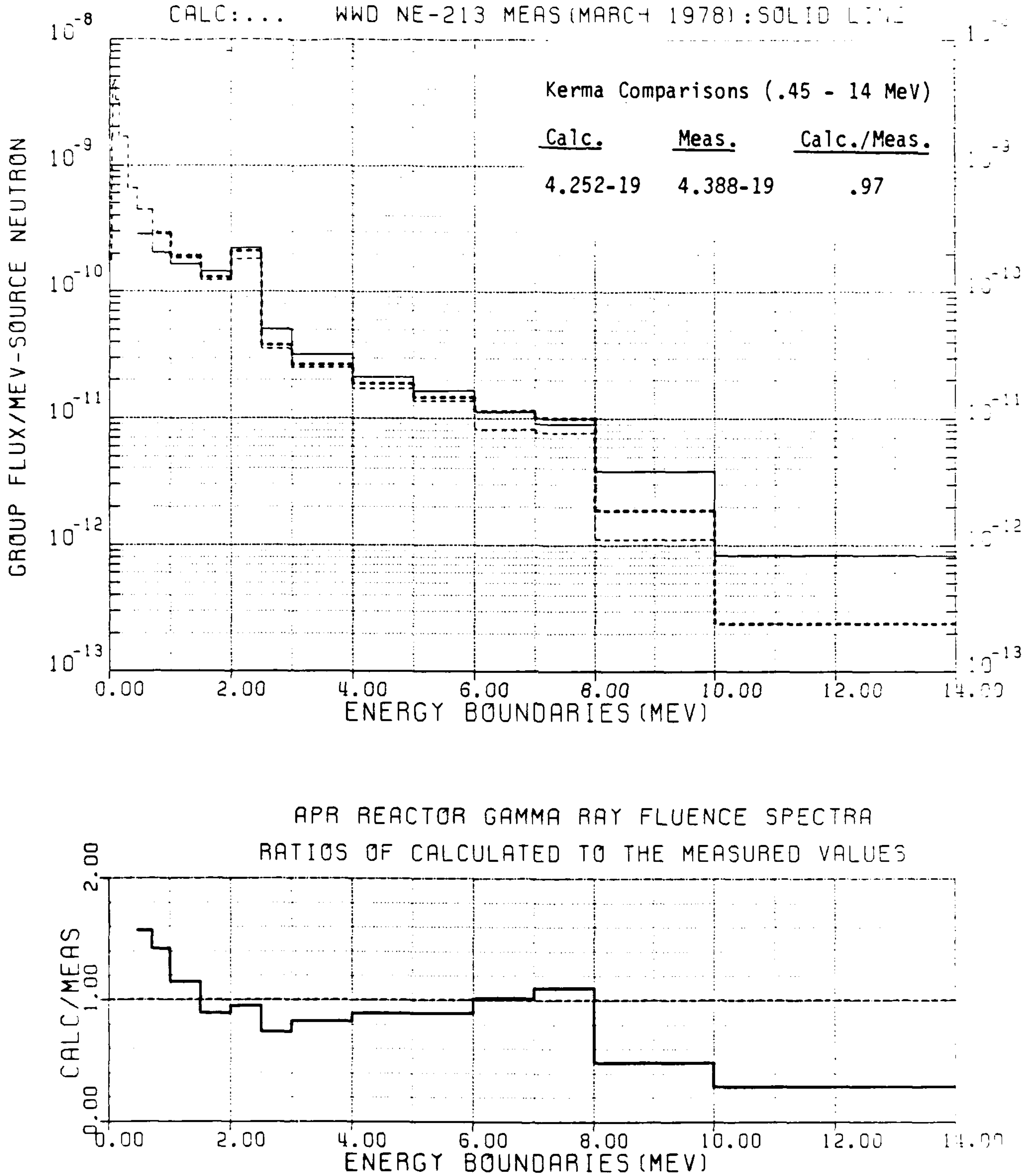


Figure 34. APR reactor gamma ray fluence spectra, calculated and measured at 100 meters ground range (WWD, March 1978).

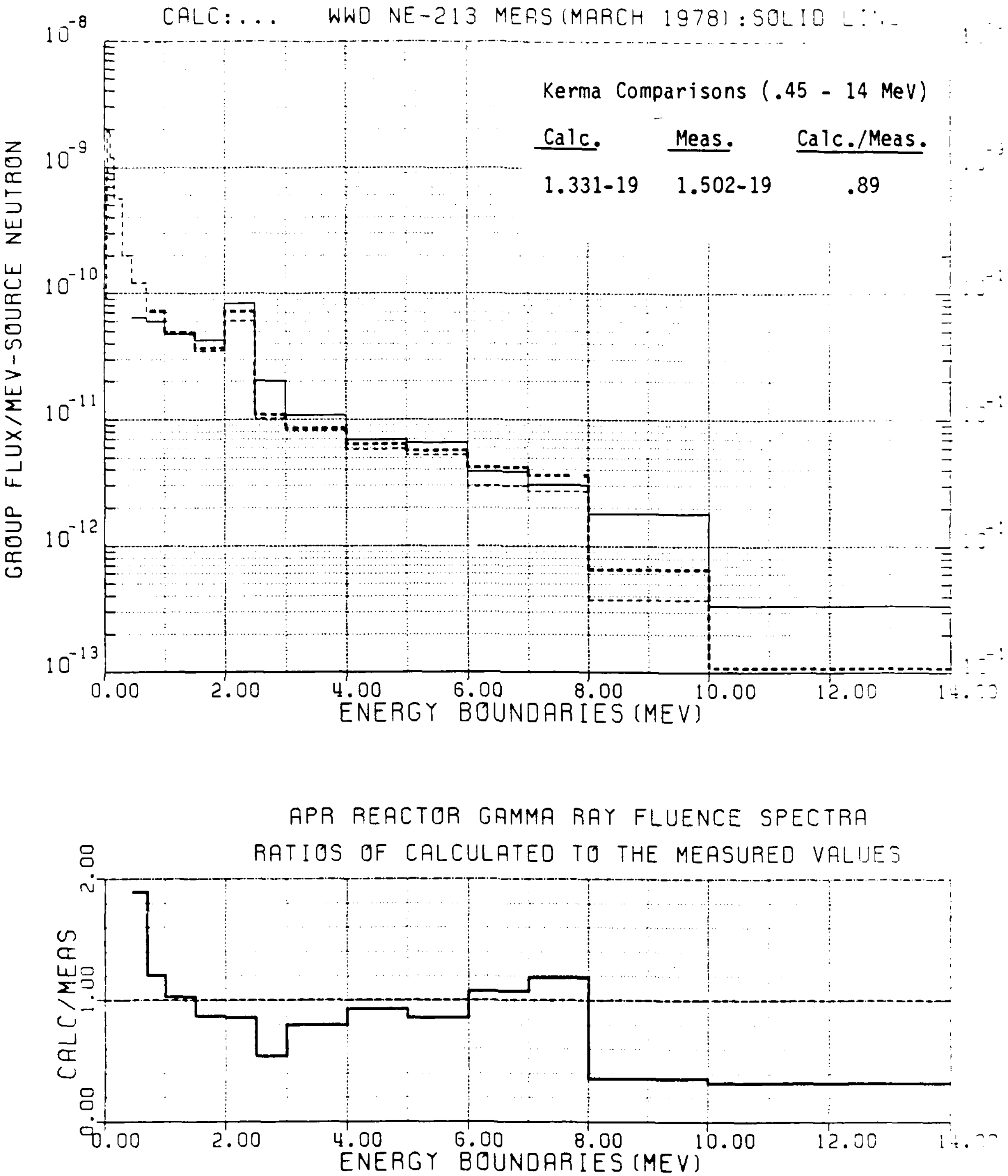
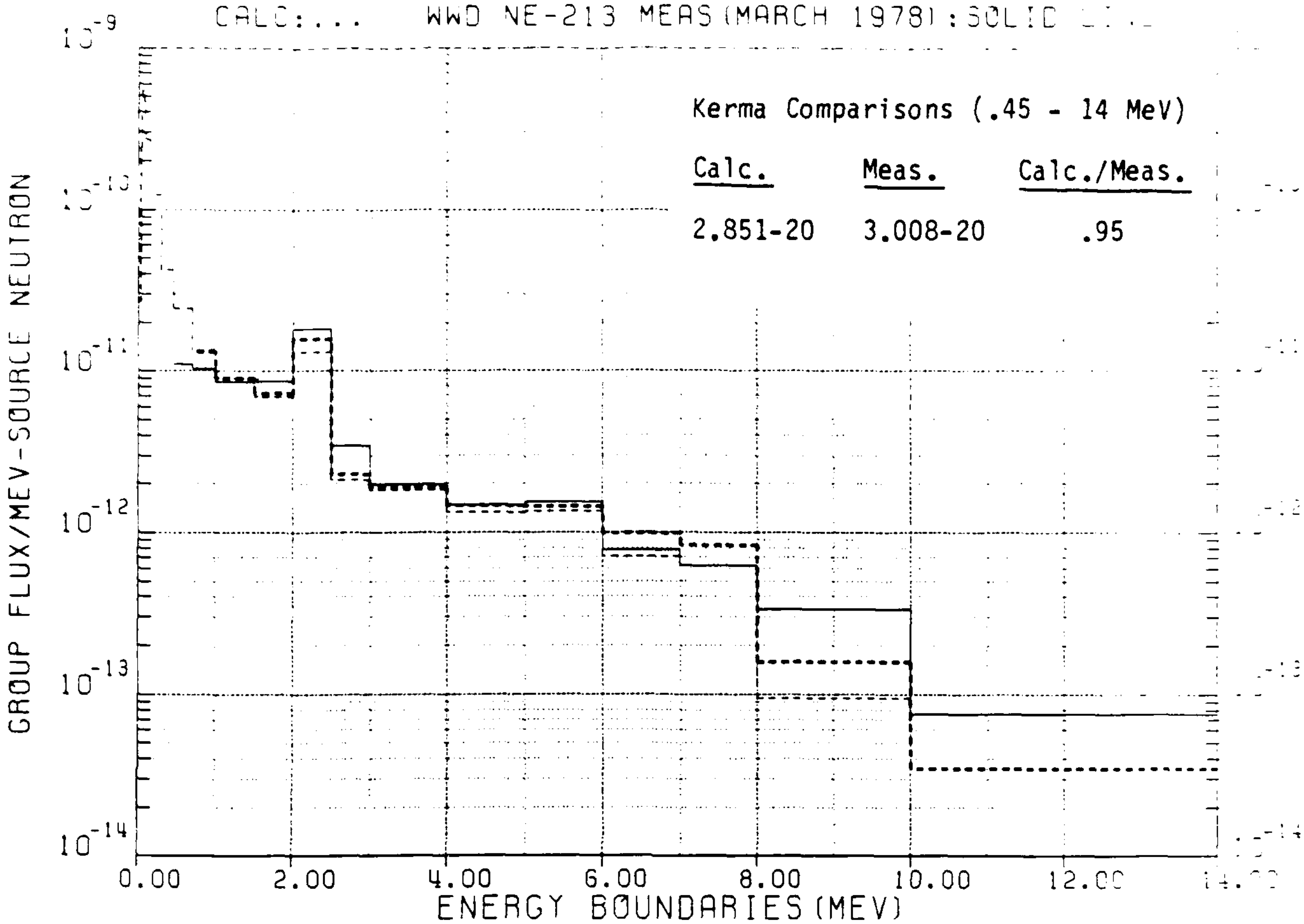


Figure 35. APR reactor gamma ray fluence spectra, calculated and measured at 170 meters ground range (WWD, March 1978).



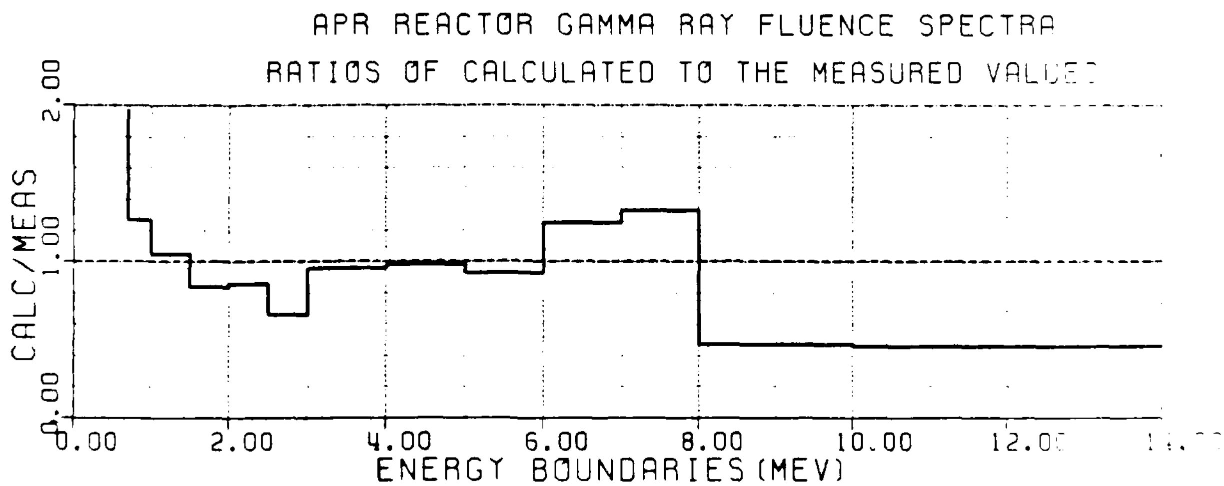
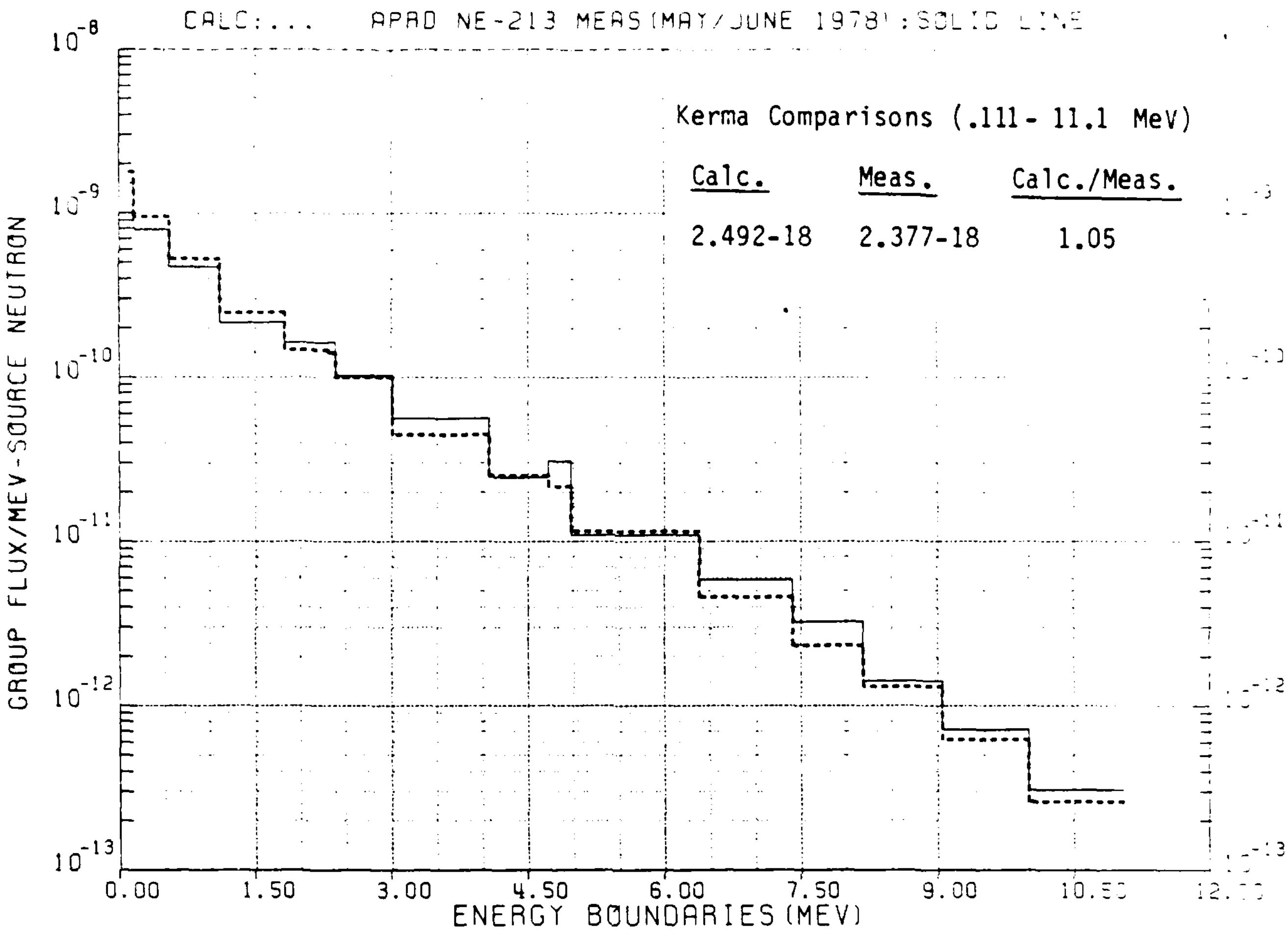


Figure 36. APR reactor gamma ray fluence spectra, calculated and measured at 300 meters ground range (WWD, March 1978).



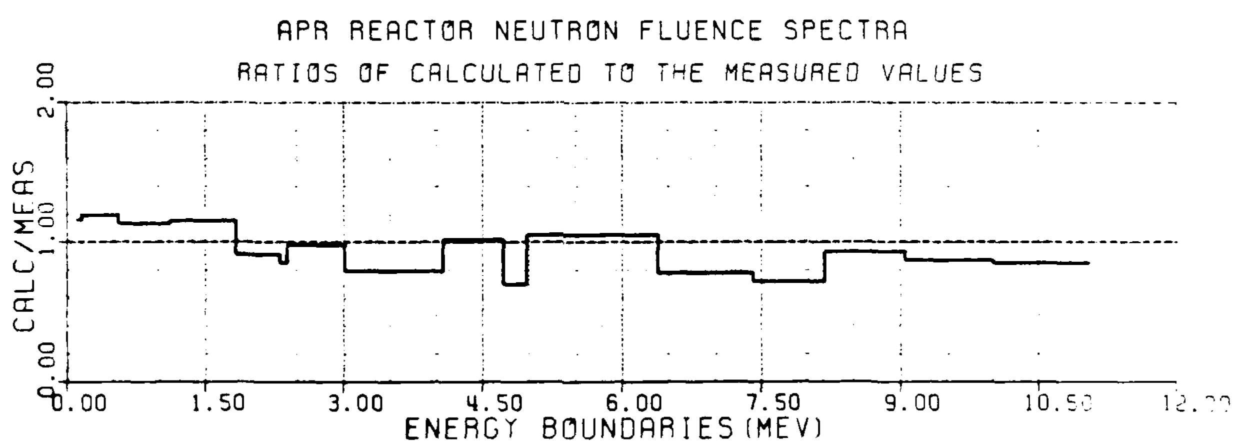


Figure 37. APR reactor neutron fluence spectra, calculated and measured at 100 meters ground range (APRD, May/June 1978).

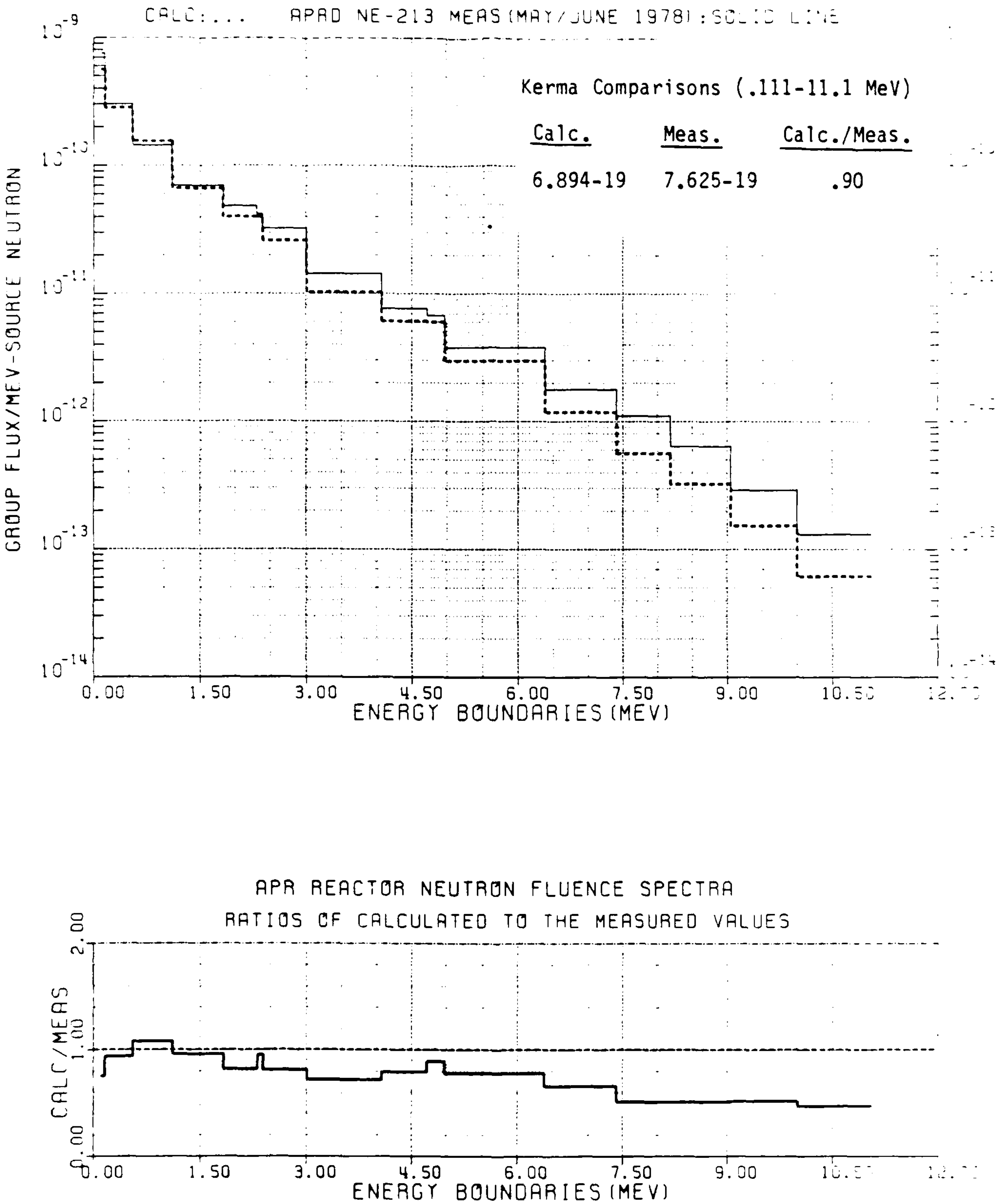
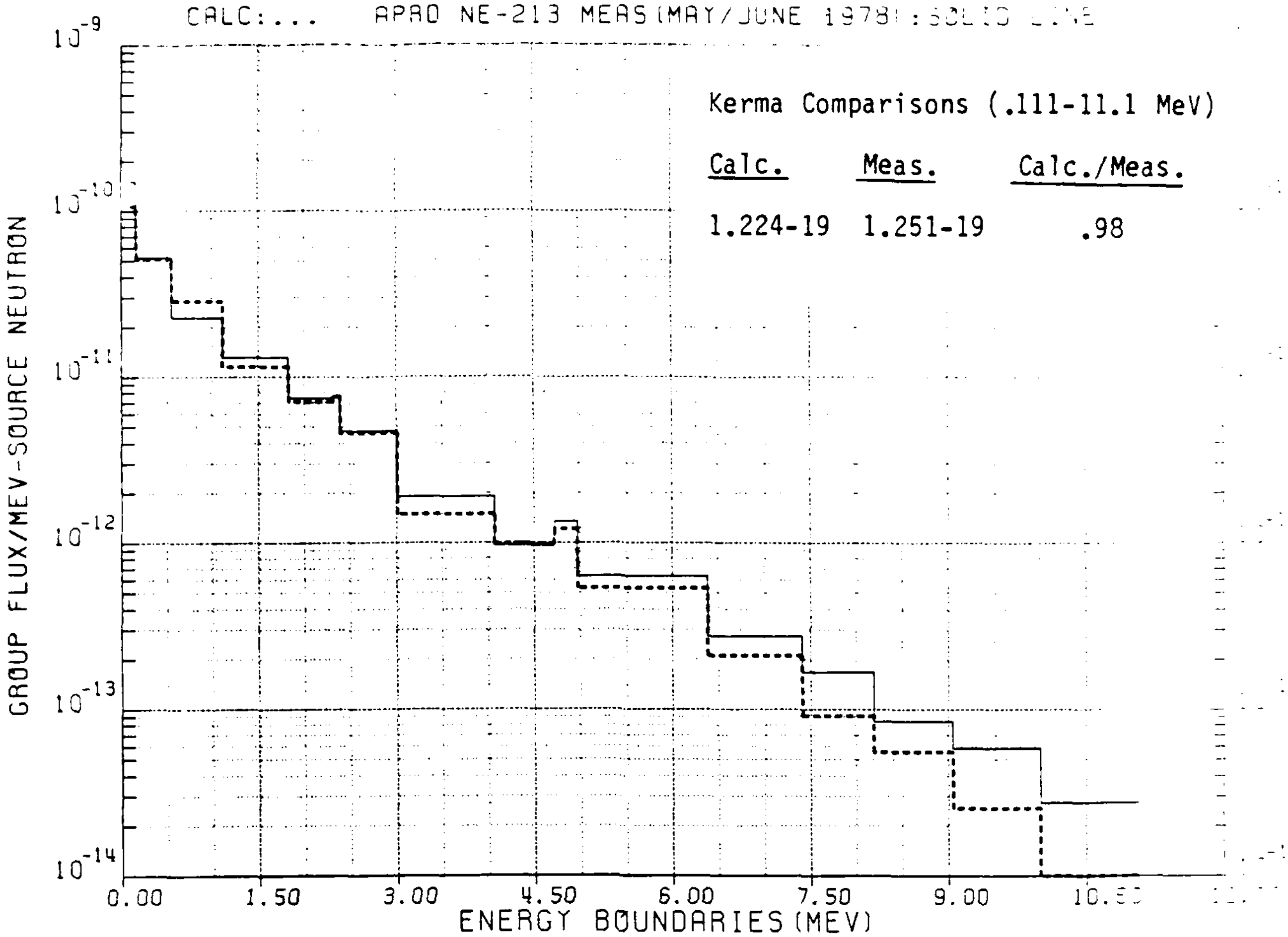


Figure 38. APR reactor neutron fluence spectra, calculated and measured at 170 meters ground range (APRD, May/June 1978).



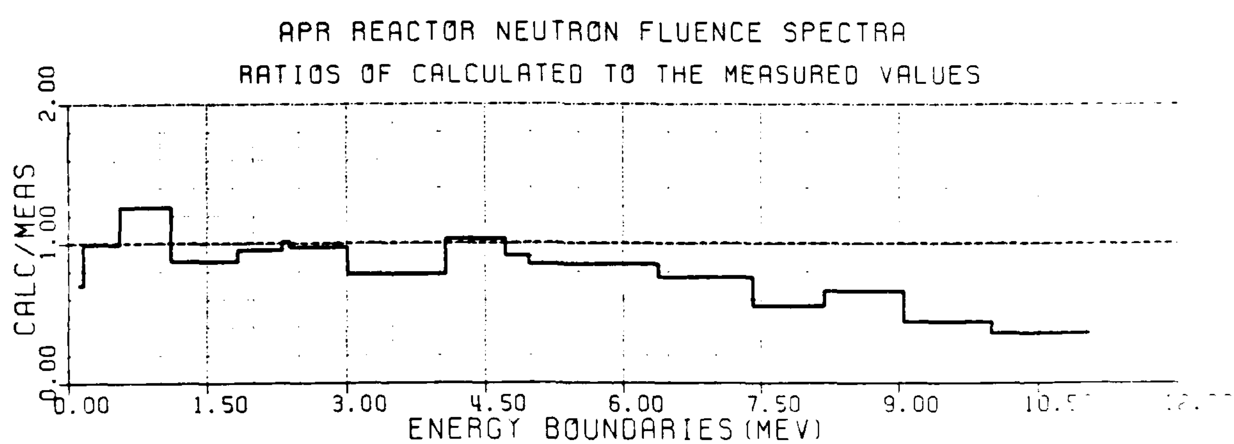


Figure 39. APR reactor neutron fluence spectra, calculated and measured at 300 meters ground range (APRD, May/June 1978).

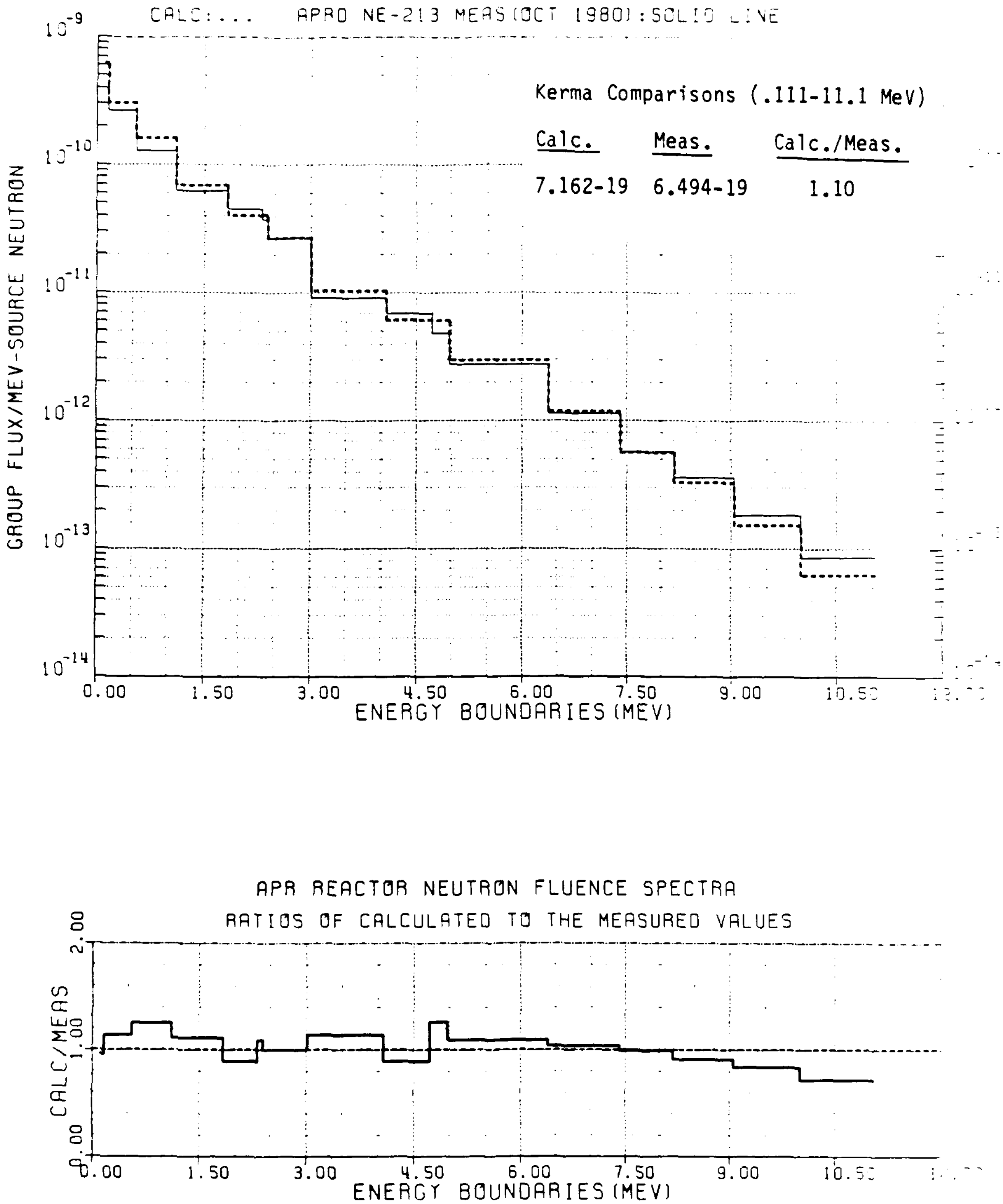


Figure 40. APR reactor neutron fluence spectra, calculated and measured at 170 meters ground range (APRD, Oct. 1980).

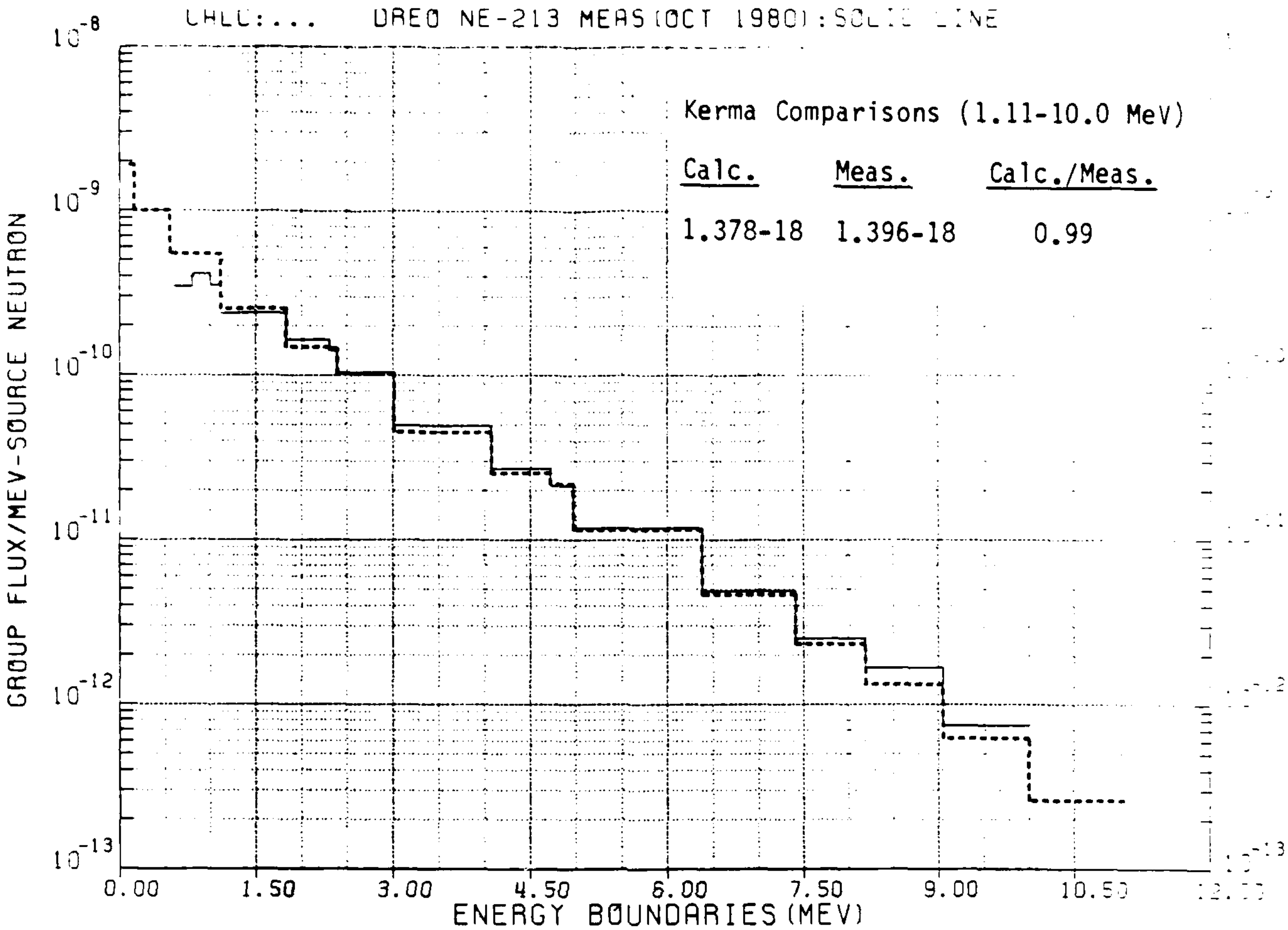
and calculated kerma arises mainly from neutrons having energies less than 2 MeV.

DREO performed NE213 measurements of neutron and gamma ray spectra in the fall of 1980 and repeated the measurement at 1080 meters in the fall of 1981. The reported spectra from these measurements were revised in 1984 based on a new neutron unfolding procedure.[30] The neutron spectra are shown as per the revised measurements and the calculations at 100, 170, 300, 400 and 1080 meters horizontal range in Figures 41 through 45 respectively.

Comparisons between the calculated and DREO-measured fluences are consistently good at the 100 and 170 meter ranges, even more so than was the case for the other two organizations. As might be expected, the calculated kerma for the energy range considered to be most appropriate for NE213 measurement ($E > 1$ MeV) also show very good agreement at these two ranges. However, at 300 and 400 meter ranges the calculation overpredicts the fluence below 2 MeV by 40% and, hence, the kerma, by 20 to 25%. Moving on to 1080 meters, substantial variations are seen between measured and calculated fluences at high neutron energies. However, measured values above 5 MeV are subject to large uncertainties due to low count rates at this distance. More interestingly, the agreement below approximately 5 MeV is no worse than for the 300 and 400 meter locations. In fact the agreement below 2 MeV is actually considerably better. Thus, the comparison of 1080 meter calculated and measured values on the basis of kerma is no worse overall than that at 300 or 400 meters.

If the discrepancy in transmitted low energy neutron fluence calculated at 300 and 400 meters were an artifact of the air or ground cross sections or of the basic calculational approach, one may reasonably expect that it would worsen with increasing range. Having found that it does not, it is suggested that the discrepancy is due to other factors not modeled in the calculation, such as the presence of trees.

The gamma ray spectra measured by DREO, as depicted by solid lines in Figures 46 through 50, show very good agreement with the calculated values at all ranges (with the addition of the neutron-induced detector gamma rays). As



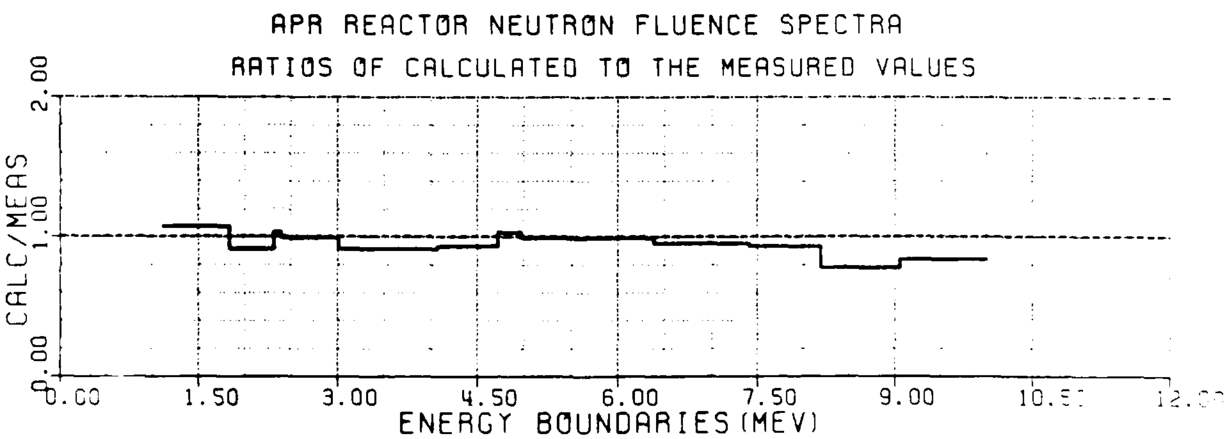


Figure 41. APR reactor neutron fluence spectra, calculated and measured at 100 meters ground range (DREO, Oct. 1980).

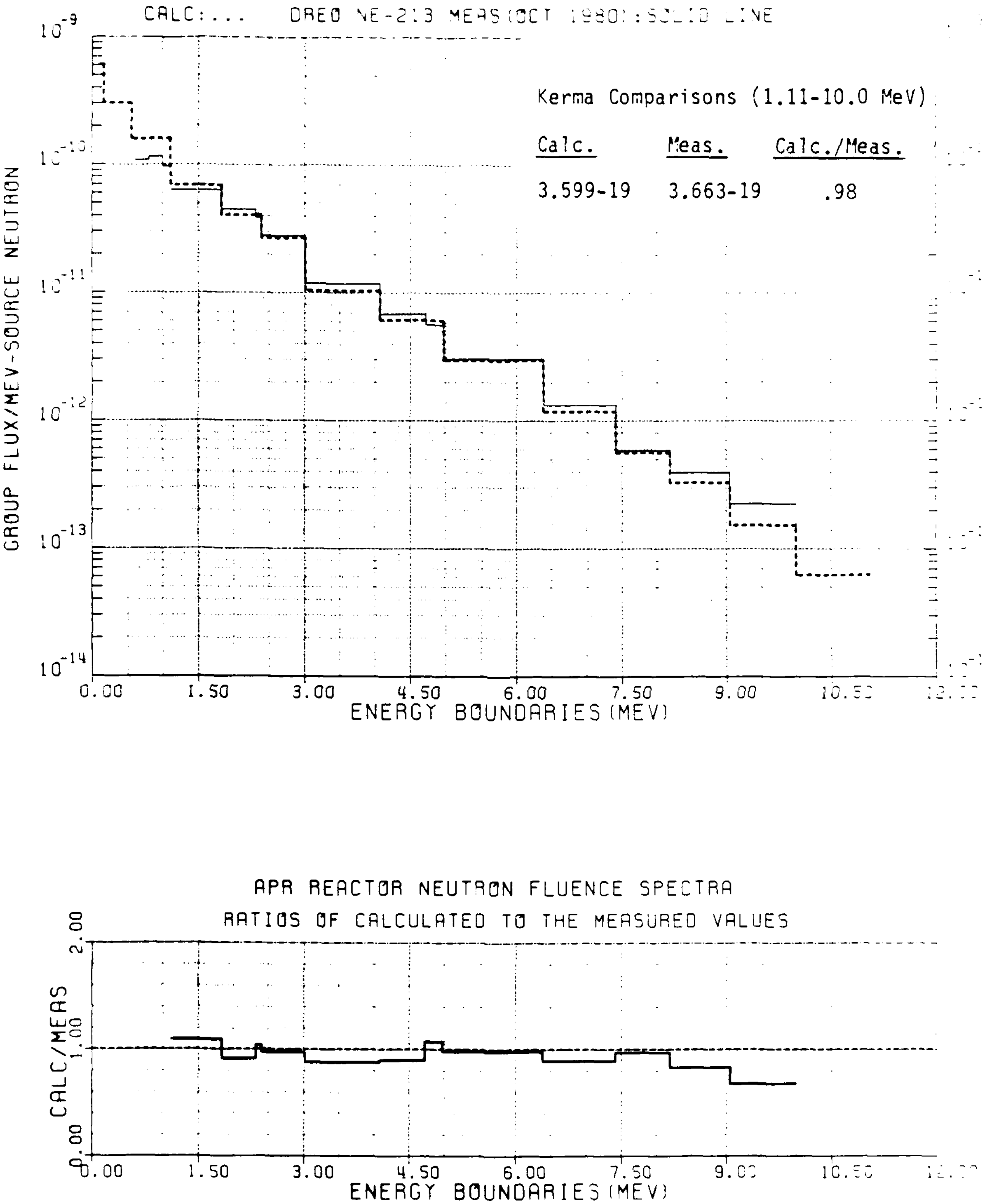


Figure 42. APR reactor neutron fluence spectra, calculated and measured at 170 meters ground range (DREO, Oct. 1980).

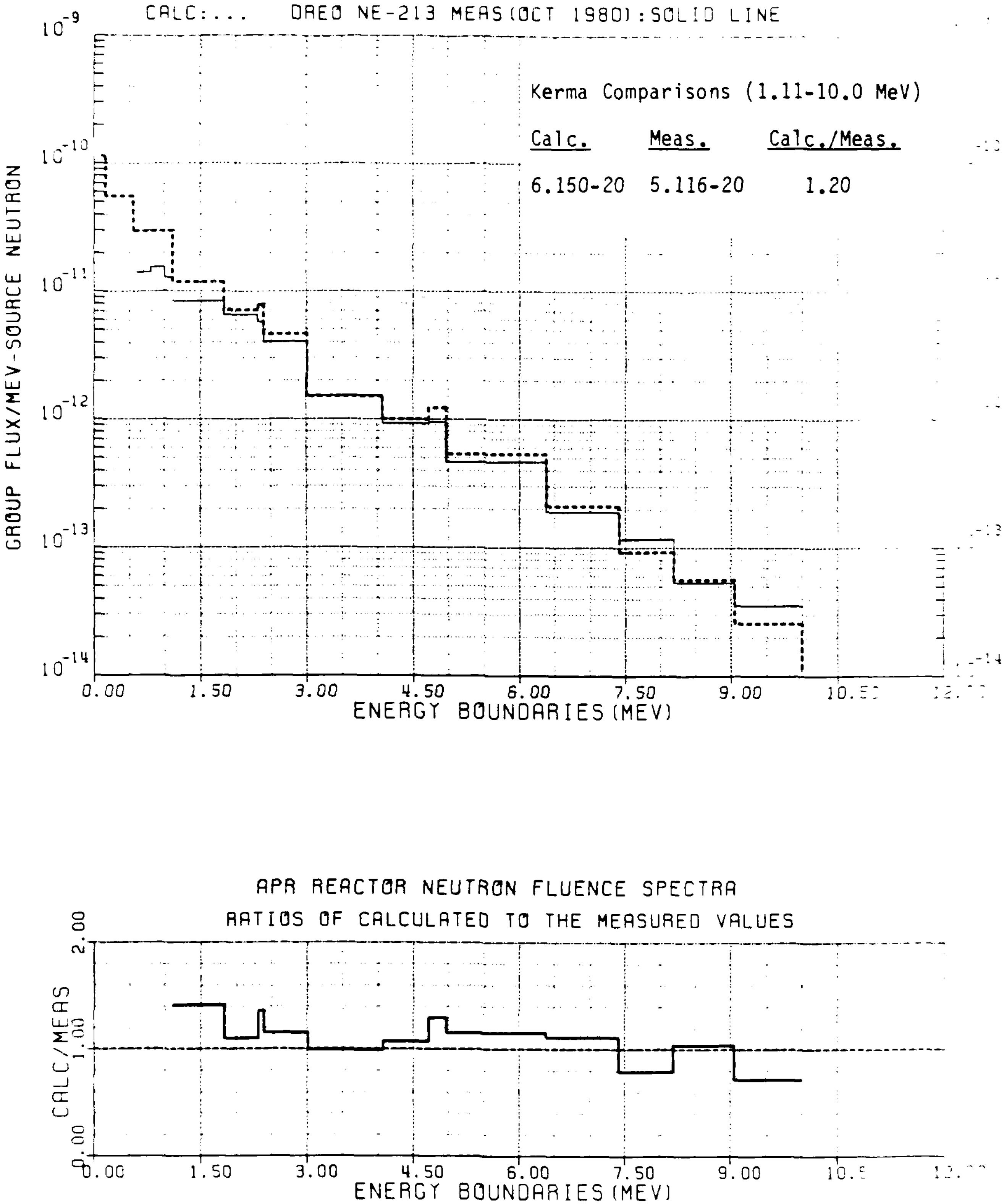


Figure 43. APR reactor neutron fluence spectra, calculated and measured at 300 meters ground range (DREO, Oct. 1980).

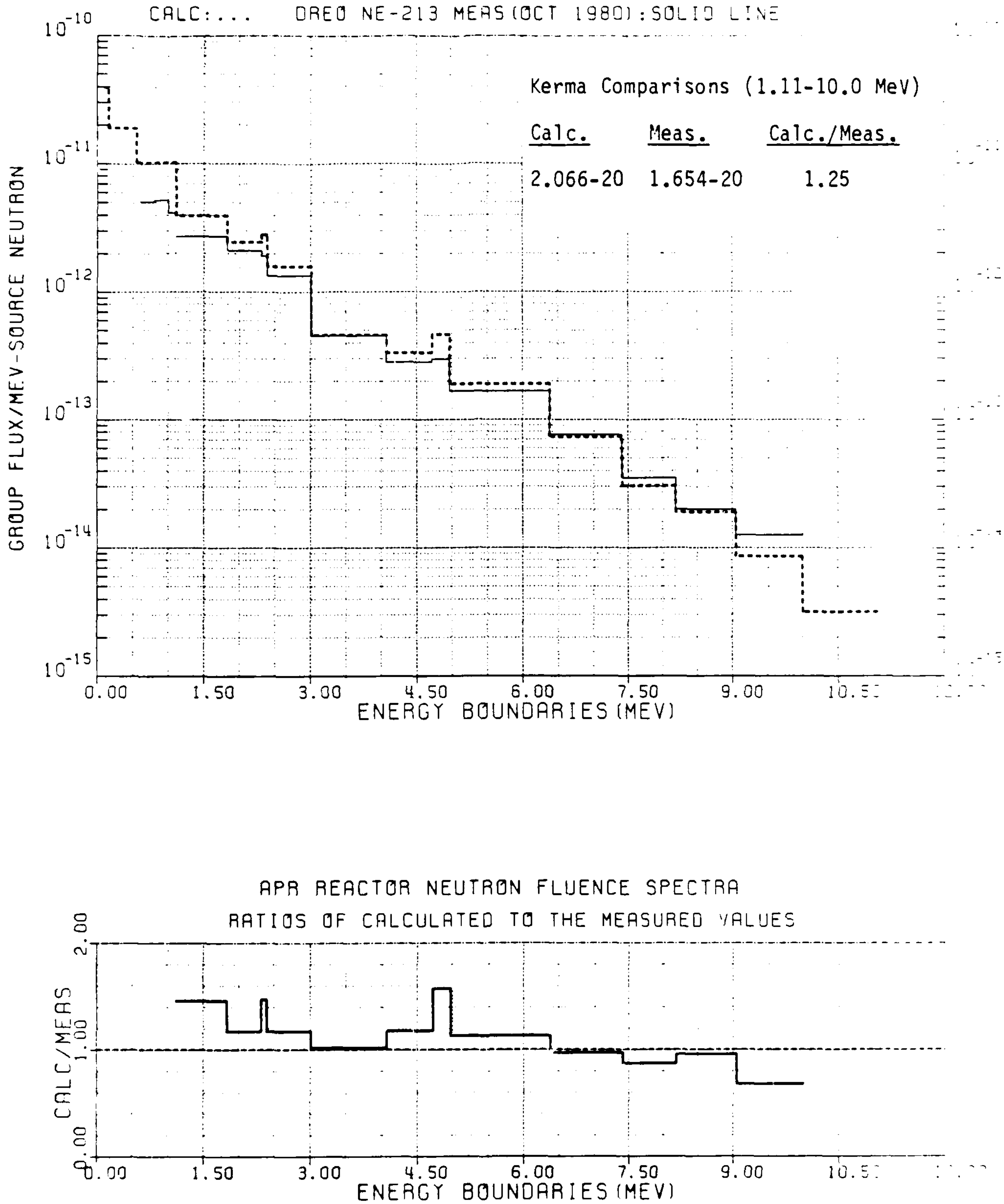
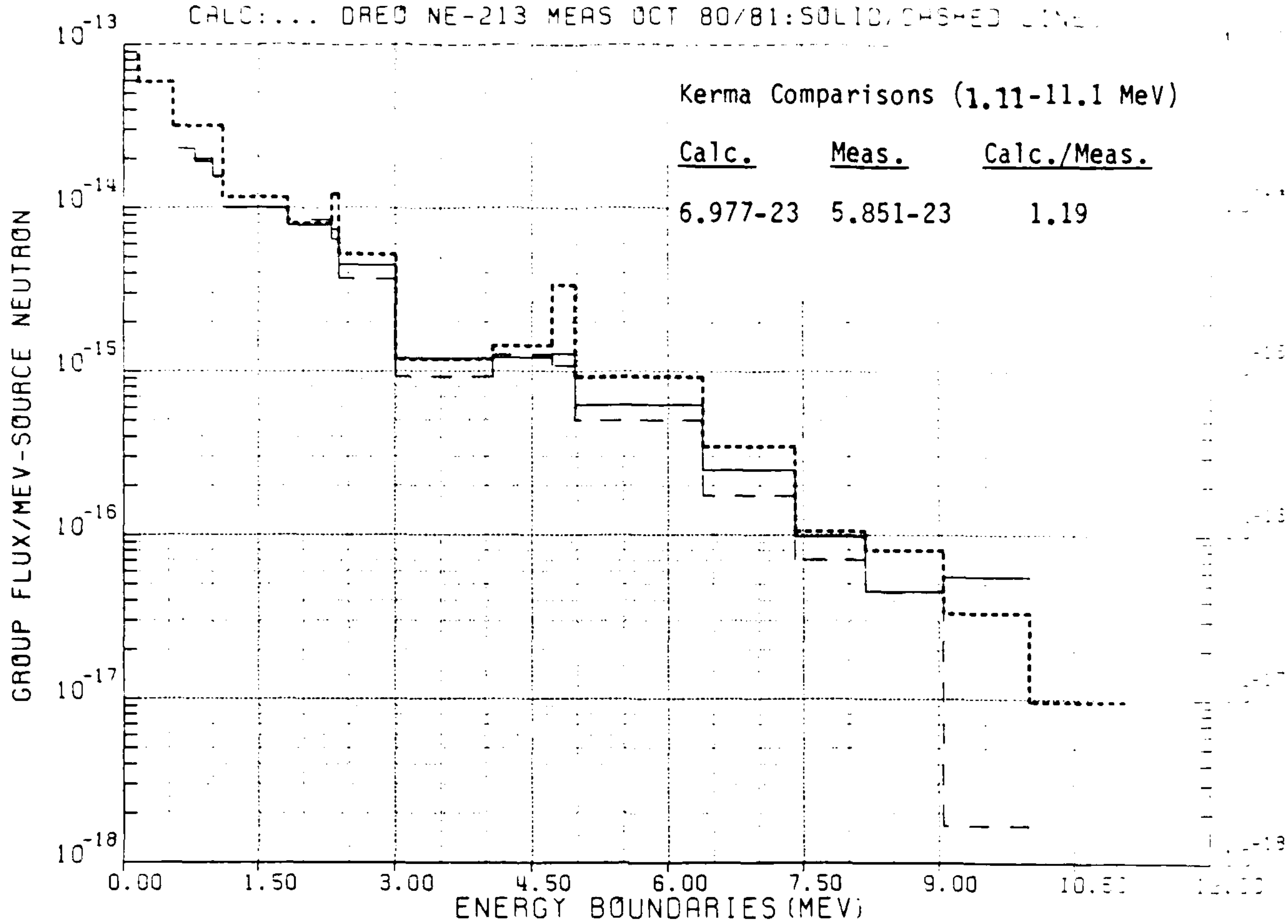


Figure 44. APR reactor neutron fluence spectra, calculated and measured at 400 meters ground range (DREO, Oct. 1980).



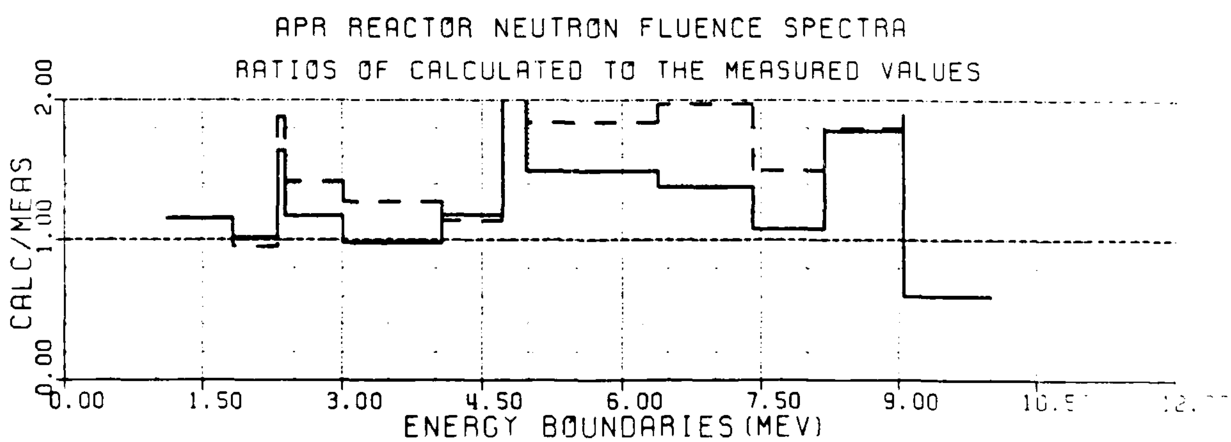


Figure 45. APR reactor neutron fluence spectra, calculated and measured at 1080 meters ground range (DREO, Oct. 1980/1981).

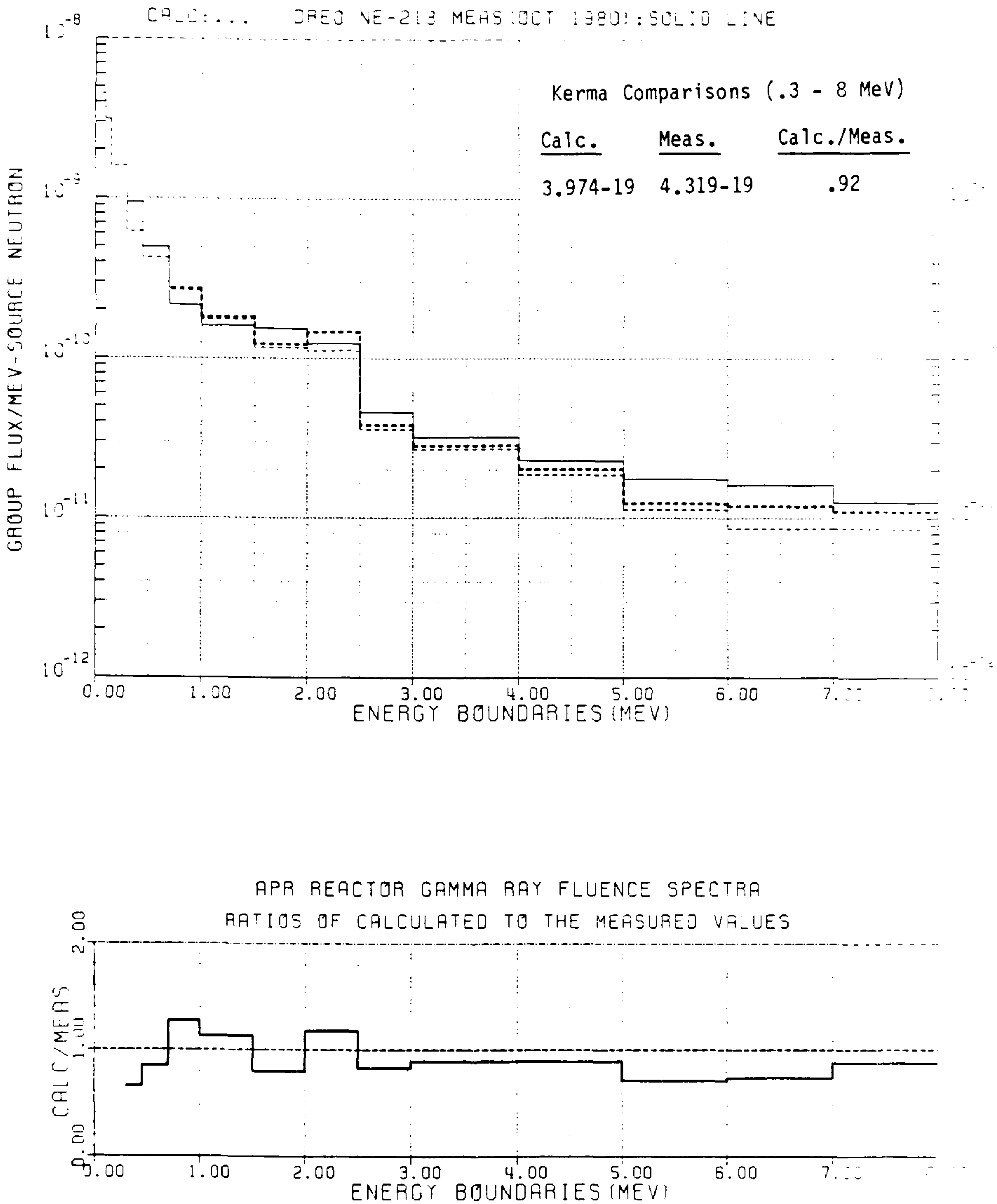


Figure 46. APR reactor gamma ray fluence spectra, calculated and measured at 100 meters ground range (DREO, Oct. 1980).

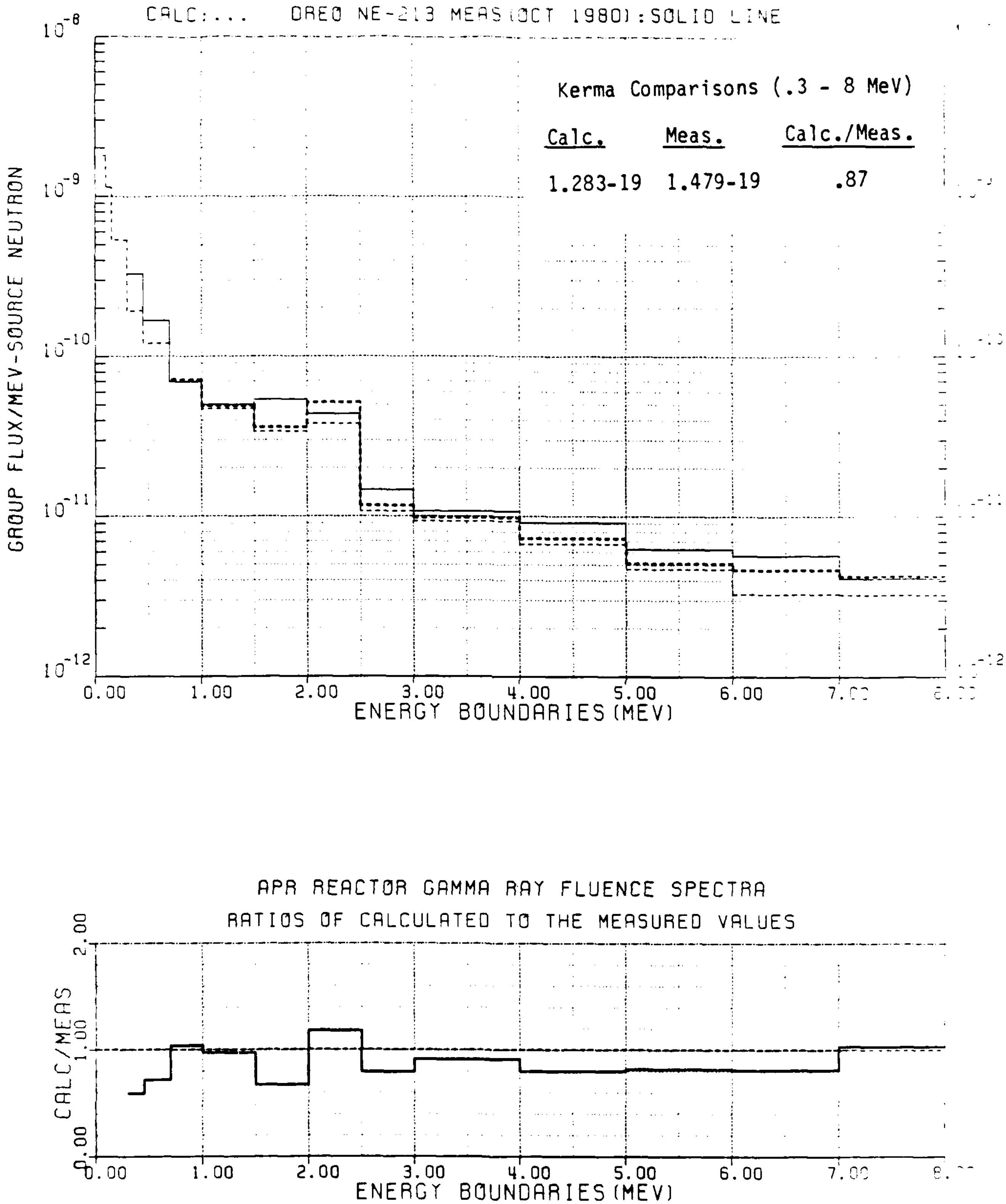


Figure 47. APR reactor gamma ray fluence spectra, calculated and measured at 170 meters ground range (DREO, Oct. 1980).

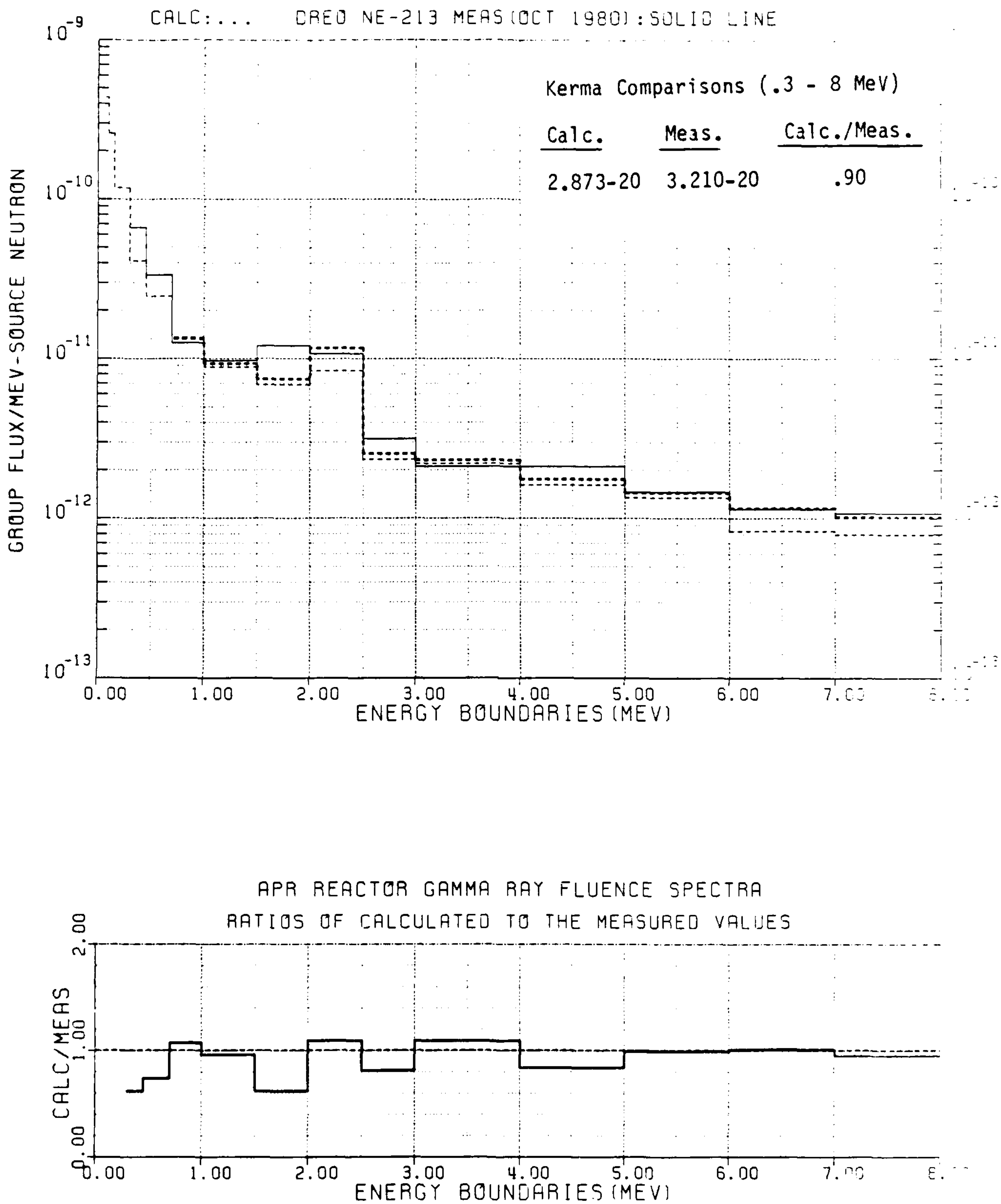


Figure 48. APR reactor gamma ray fluence spectra, calculated and measured at 300 meters ground range (DREO, Oct. 1980).

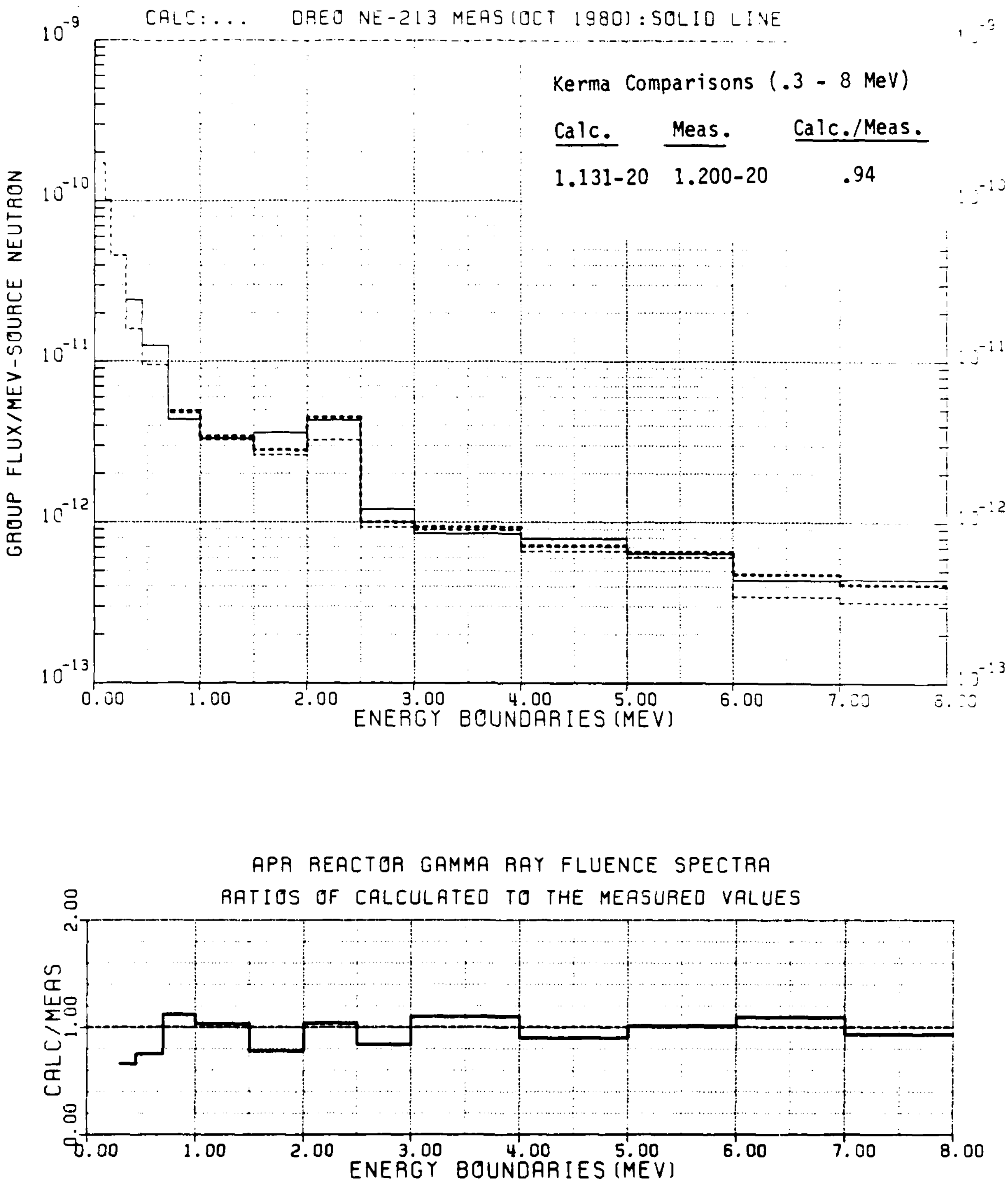
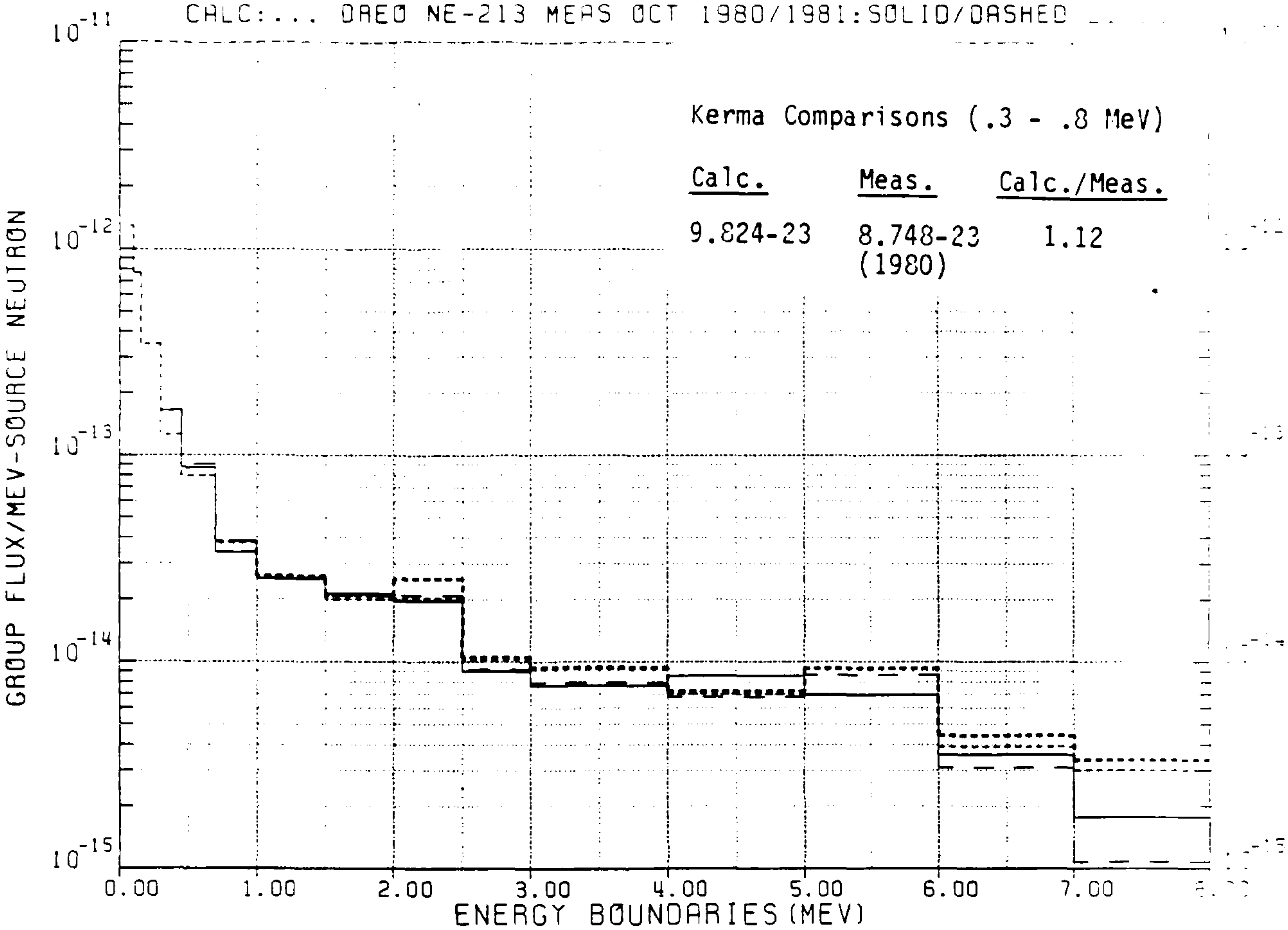


Figure 49. APR reactor gamma ray fluence spectra, calculated and measured at 400 meters ground range (DREO, Oct. 1980).



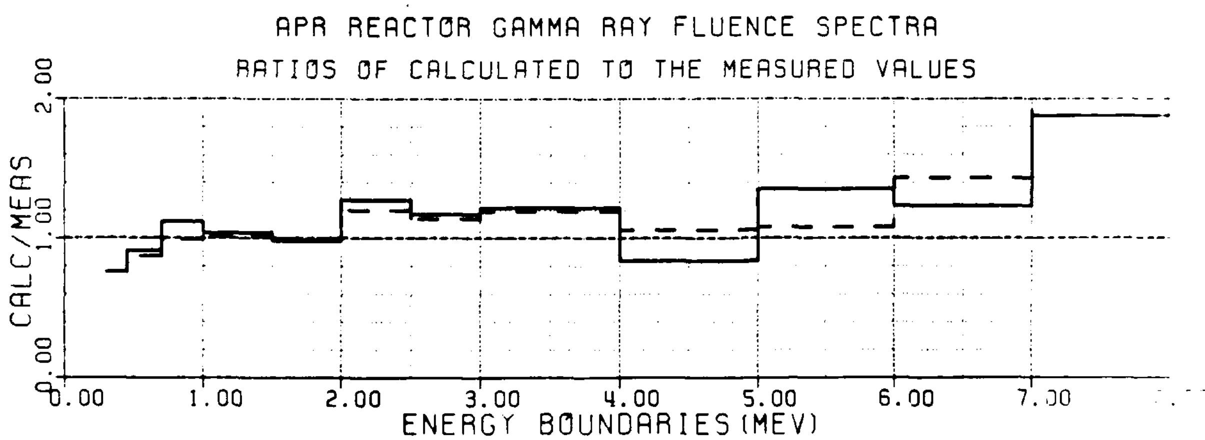


Figure 50. APR reactor gamma ray fluence spectra, calculated and measured at 1080 meters ground range (DREO, Oct. 1980/1981).

is the case for gamma ray measurements by other organizations, using the NE213, the comparison worsens for energies less than 0.7 MeV, which is the extreme low end of the detectors supposed effective range. Also, at ranges other than 400 meters the hydrogen-capture gamma ray peak has apparently been shifted downward in the measurement. This suggests that either the energy resolution of these measurements is very broad or a shift in calibration energy is in evidence. In any event those spectral discrepancies seem to be minor overall, which is reflected in the excellent agreement of measured and calculated kerma.

DREO also performed thermal and epithermal neutron fluence measurements using the BF_3 detector, both bare and cadmium covered. The results of these measurements in terms of counting rates have been communicated to SAIC, along with the BF_3 efficiencies as a function of neutron energy.[31] Measurement results are shown in Table 9 in terms of cadmium-covered BF_3 count rates and the cadmium-difference BF_3 count rate. Calculations of these count rates were performed by collapsing the point detector efficiencies into a few-group format using a 1/E energy distribution to 5 kT with a Maxwellian tail (T = 300°K). The results of these calculations and their relationship to the measurements are also shown in Table 9.

The general agreement between the measured and calculated cadmium-covered BF_3 count rate is not bad at any range. However, there are some definite trends in the comparison, showing improving agreement with increasing range and excess calculated values only at the middle ranges (in the trees). The 100 meter comparison reflects the fact that the low energy end of the neutron source spectrum may not be a good replica for the actual reactor source, even though the thermal comparison indicates an overall acceptable down-scattering term from the higher energies. Additionally, the anisotropy of the reactor leakage spectrum was not modeled in the calculations. The measurements have indicated that the polar distribution of the leaking neutrons is somewhat peaked at the mid-plane of the reactor.

Table 9. Measured and calculated BF_3 counting rates at the APR reactor

Ground Range (M)	Epithermal Cadmium-covered BF_3 (C/kWh)			Thermal Cadmium-Difference BF_3 (C/kWh)		
	Measured	Calculated	Calc./Meas.	Measured	Calculated	Calc./Meas.
100[b]	1.35+7[a]	1.01+7	0.75	1.62+8	1.53+8	0.94
170[b]	5.07+6	4.27+6	0.84	5.83+7	6.07+7	1.04
300[b]	9.84+5	1.10+6	1.12	1.38+7	1.45+7	1.05
400[b]	3.83+5	4.35+5	1.14	4.85+6	5.63+7	1.16
1080[b]	1.79+3	1.66+3	0.93	1.47+4	2.11+4	1.44
1080[c]	1.73+3	1.66+3	0.96	1.56+4	2.11+4	1.35

a. read as 1.35×10^7
b. Oct. 80 measurement
c. Oct. 81 measurement

Comparison of calculated and measured cadmium-difference shows a similar trend to those for the Cd-BF_3 in that calculated values increase relative to the measurements with increasing range. However, in this case agreement is better close in, while at the largest range the calculation is significantly larger than the measurement. One would expect that this overestimate of thermal neutrons would cause a matching overestimate in the calculation of hydrogen capture gamma rays relative to those calculated at shorter ranges. If one takes the gamma energy range for this comparison to be 2 to 3 MeV to allow for detector resolution in the regrouped format, it can be seen from Figure 50 and those preceeding it that such an overestimate appears to be in evidence. However, it is also possible that the 1080m detector location, being on the crest of a small hill, may be characterized by less soil mositure that those in the first 400 meters. That would explain the good agreement between calculated and measured epithermal neutron fluence and the simultaneous over estimate of the thermal neutrons as represented by the calculations.

SECTION 4

SUMMARY AND CONCLUSIONS

The work reported herein began as an attempt to demonstrate the adequacy of calculational methods in reproducing BREN experimental measurements of neutrons and gamma rays fromisotopic and reactor sources. That portion of the effort ended with satisfactory agreement between Co-60 gamma ray field and reactor neutron field calculations and measurements. However, an outstanding discrepancy was left for reactor gamma ray field values. The calculation of APR, a very similar reactor experiment to BREN, was attempted in hopes of clearing up this issue. The results of the APR analysis indicate excellent agreement between measured and calculated gamma rays both on a kerma and a spectral basis. It is therefore concluded that the BREN gamma ray measurements performed in a mixed neutron-gamma ray field are too high. A possible cause for this is that the PHIL detector readings were contaminated by thermal neutrons even though the experimental plan called for the system to be shielded against them.

Measurements of neutrons at APR have turned up a new set of discrepancies with respect to the calculated results. The calculated values appear to be consistently higher than the measurements, particularly at 300 and 400 meter ground range. It should be noted that those ranges correspond to locations within the 20 meter wide path through the forest which rings the reactor site. In order to establish the effect of the forest on a more quantitative basis, APRD performed a series of measurements at the 400 meter point at detector heights of 2, 12 and 22 meters above the ground in November of 1982.[32] These measurements were performed with the NE213 and the results for neutrons are plotted together with calculational results in Figures 51, 52 and 53 for the three heights. Resolution of the neutron spectral measurements appears to breakdown beyond 12 MeV. Agreement between calculation and measurement is good between 3 and 12 MeV. Below 3 MeV the comparison is not good. It is also not consistent over the three detector heights. However, if one takes only the energy range between 3 and 10 MeV, a region which avoids NE213 spectral unfolding controversies, the measured data show a definite trend relative to the calculations. This trend indicates that the forest does indeed increase the neutron fluence gradient near the ground. Calculational

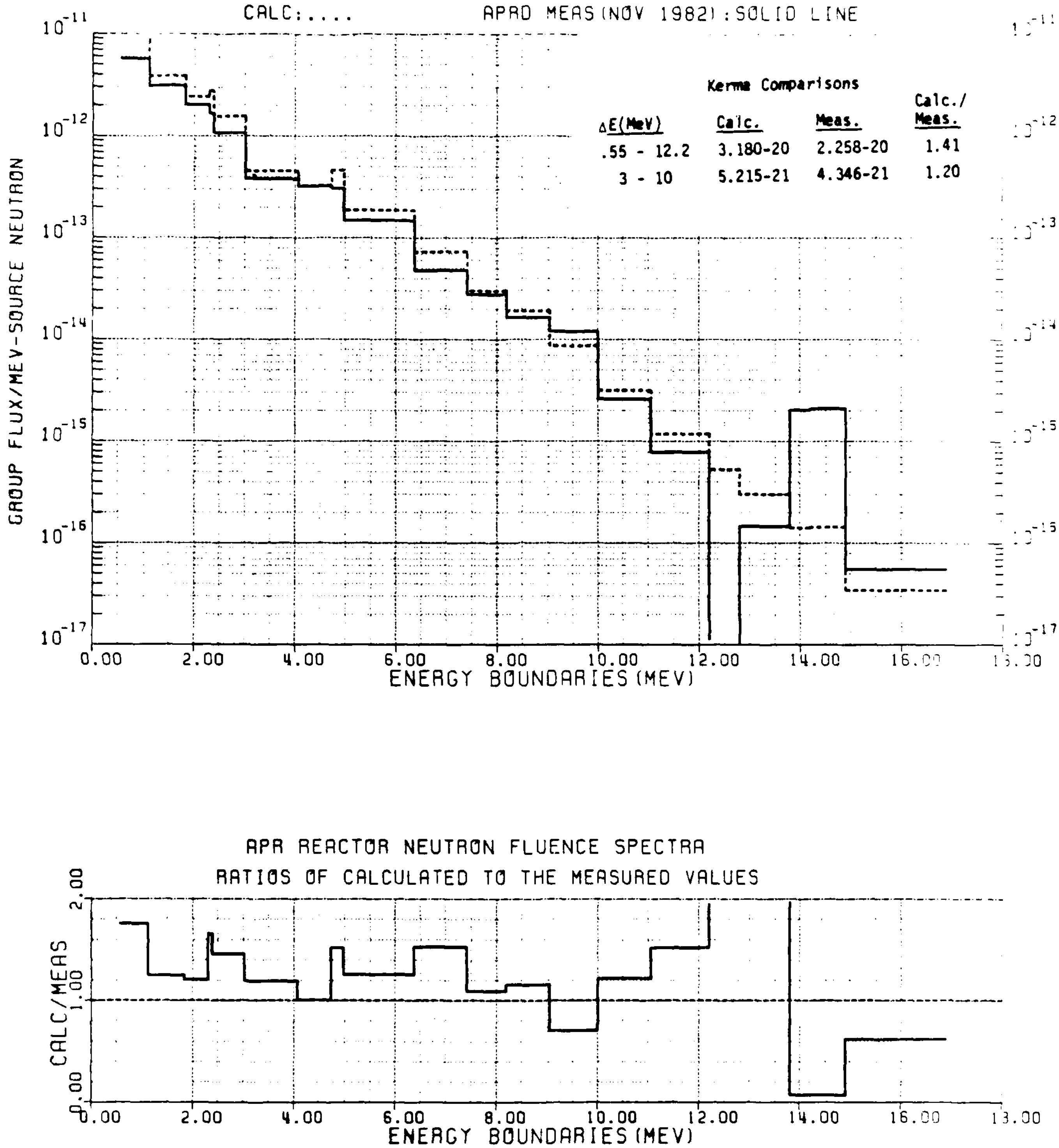


Figure 51. APR reactor neutron fluence spectra at 2 meter detector height, calculated and measured at 400 meters ground range (APRD, Nov. 1982).

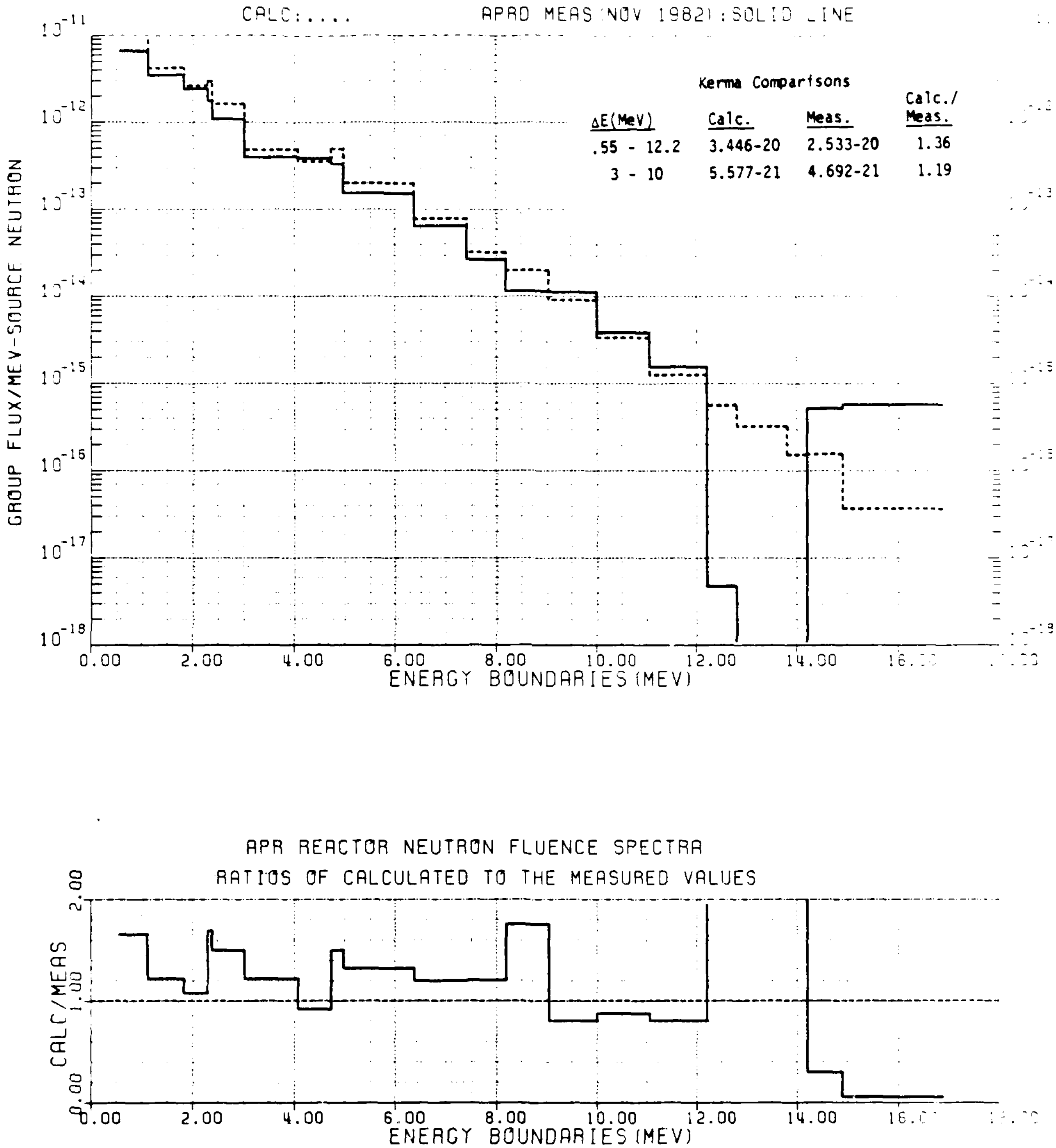
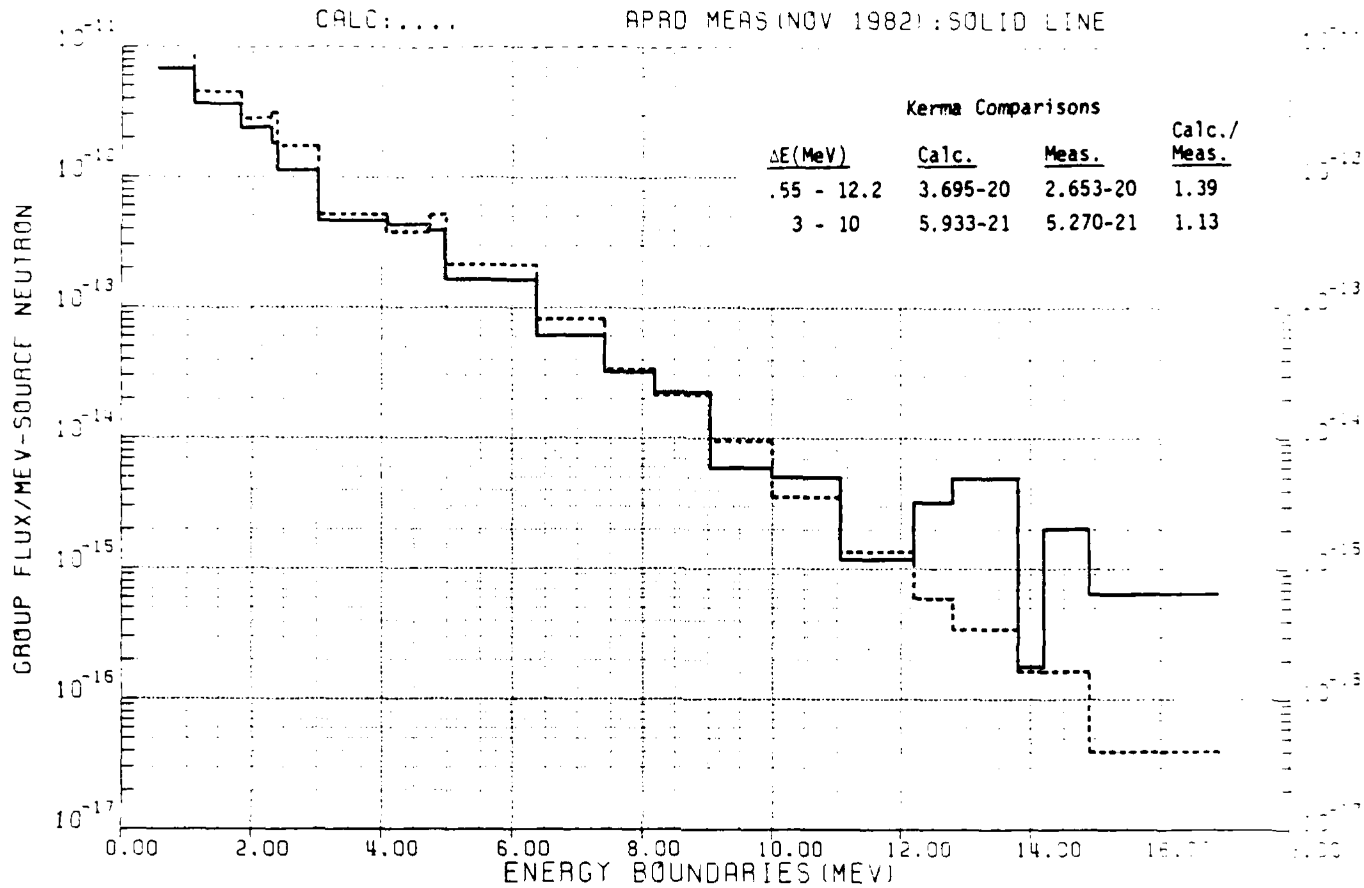


Figure 52. APR reactor neutron fluence spectra at 12 meter detector height, calculated and measured at 400 meters ground range (APRD, Nov. 1982).



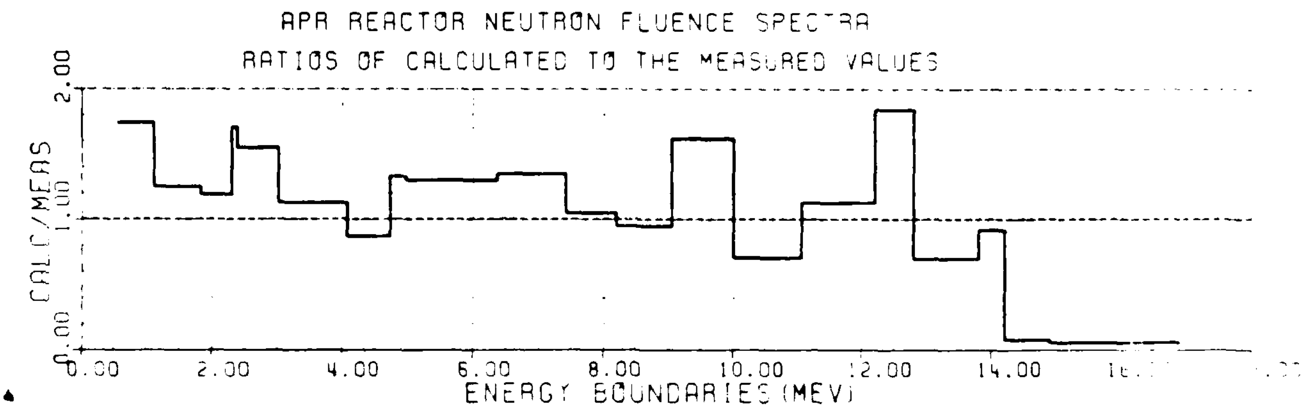


Figure 53. APR reactor neutron fluence spectra at 22 meter detector height, calculated and measured at 400 meters ground range (APRD, Nov. 1982).

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AIR-OVER-GROUND GEOMTT (U) SCIENCE APPLICATIONS
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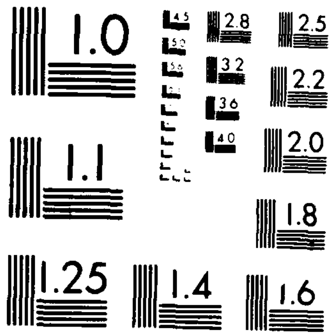
UNCLASSIFIED 01 JUN 83 SAIC-83-1200 DNA-TR-81-281 F/G 7/5 NL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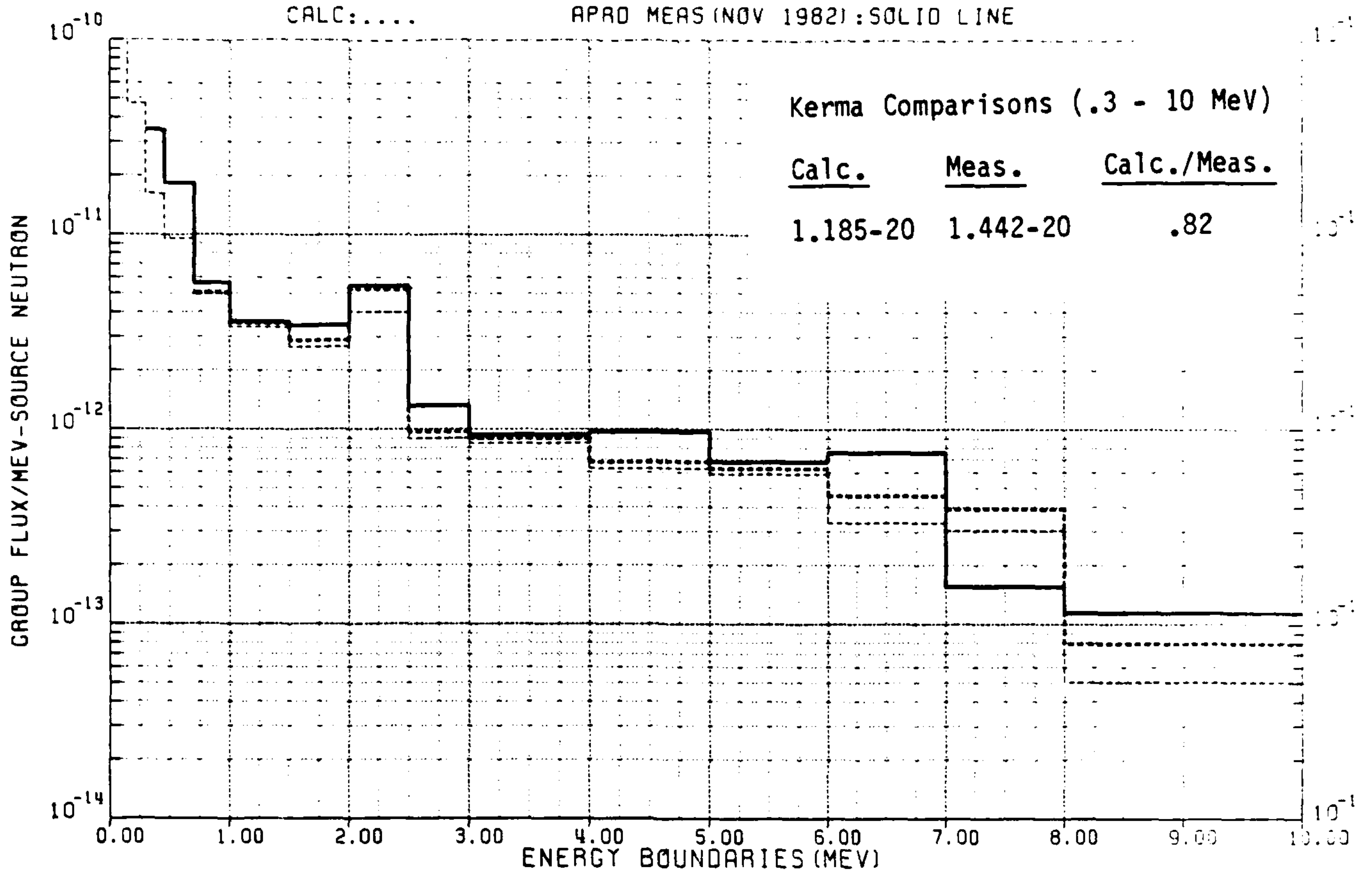
analysis has also determined that a similar effect could be obtained by increasing the soil moisture content. However, the chosen soil moisture produced a good match of calculated and measured hydrogen gamma rays as shown in Figures 54 through 56, whereas the content required to match the neutron fluence gradient measurements resulted in a significant over-prediction of this component.

Having explained a portion of the calculation-measurement discrepancy there still remains the discrepancy for neutron energies below approximately 2 MeV, which exists particularly at 300 and 400 meters. That discrepancy is particularly apparent in the DREO measurements. Its existence is supported by the most recent APR measurements using the NE213 and even more recently using Bonner spheres.[33] It is also supported to some extent by the BREN measurement results, in the form of consistent overprediction of kerma by calculations relative to measurements made above ground level, though not to the extent shown by DREO. On the other hand the WWD measurements support no such discrepancy. These spectral discrepancies are as yet unresolved, but may be removed when the trees are cut back, as planned, and the neutron fluence remeasured.

In summary, this effort has confirmed the capability of radiation transport codes to accurately predict the kerma and spectra of gamma rays from isotopic and reactor sources to large distances in air-over-ground geometries. On the other hand it has identified a potential problem in the computation of neutron transport in the energy range of 0.1 to 2 MeV. This problem results in relatively small overall uncertainties in computing kerma values for the APR and for BREN, because of the abundance of faster neutrons leaking from these assemblies. However, a much smaller percentage of neutrons of greater energies leak from the Little Boy Device because of the enormous blanket of steel which surrounded its fissionable core. This results in increased importance being associated with the transport of neutrons in the 0.1 to 2 MeV range in properly calculating the neutron kerma distribution from that device. Therefore, it is incumbant upon the measurement and calculational communities to resolve the outstanding issues which separate experimental and calculational results in this energy range, be they errors in cross sections, unfolding, or otherwise.



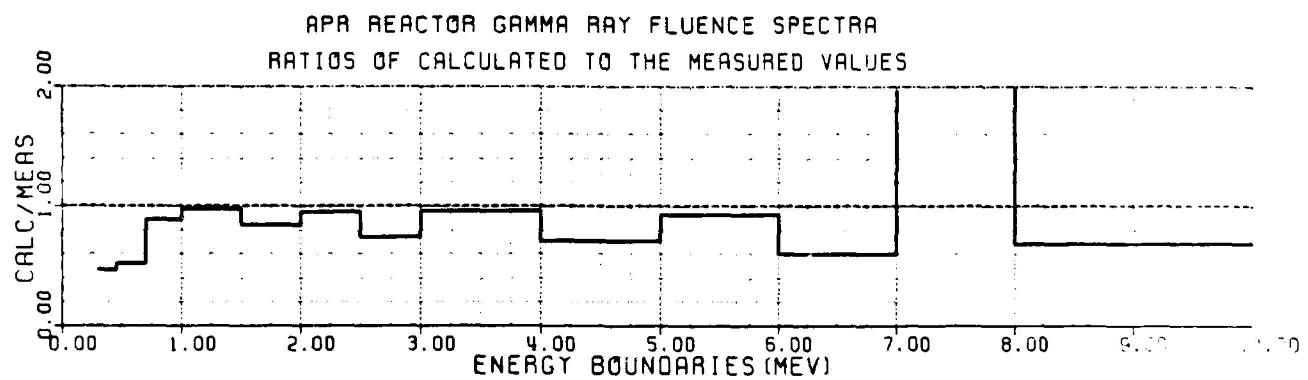


Figure 54. APR reactor gamma ray fluence spectra at 2 meter detector height, calculated and measured at 400 meters ground range (APRD, Nov. 1982).

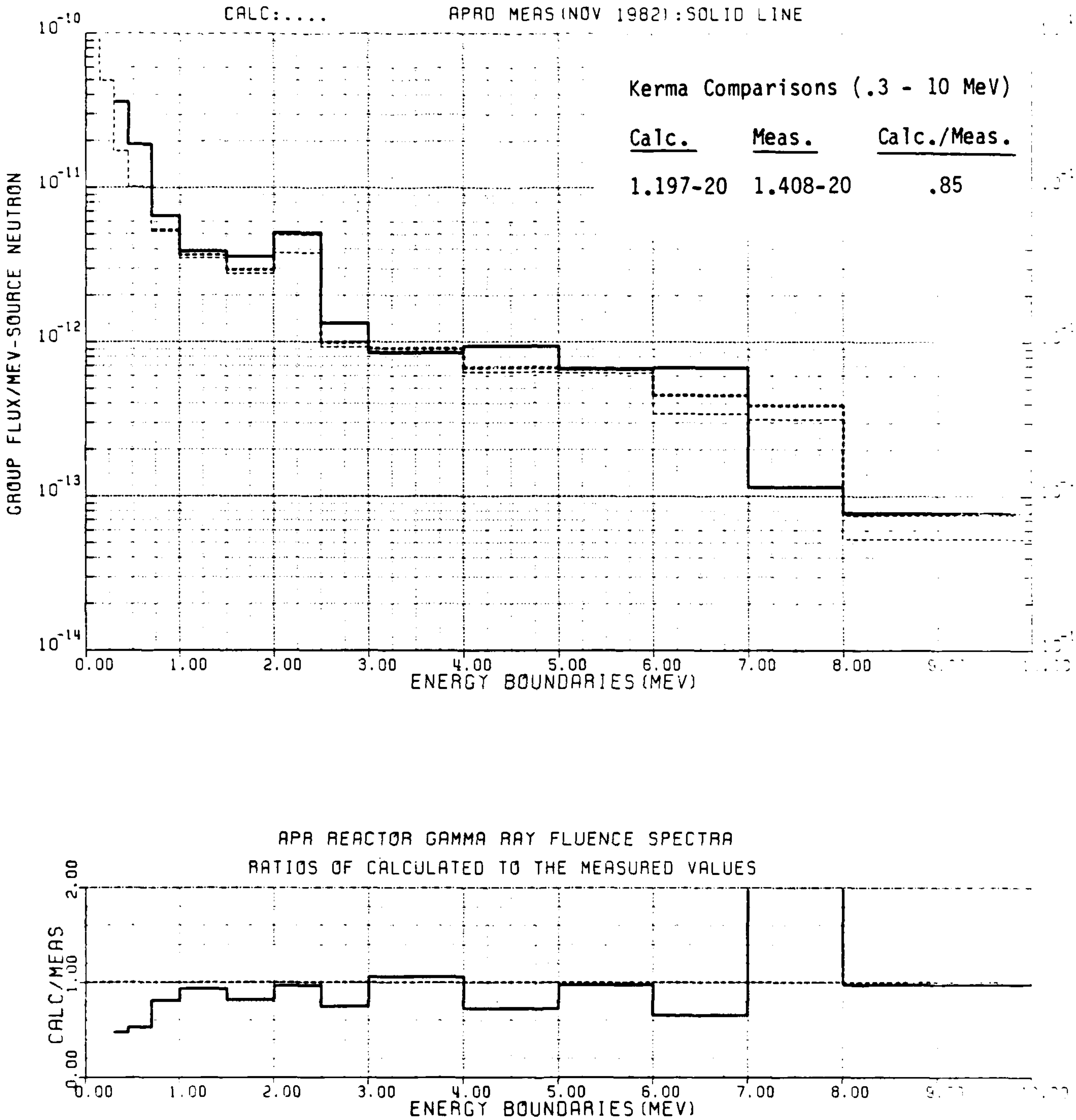


Figure 55. APR reactor gamma ray fluence spectra at 12 meter detector height, calculated and measured at 400 meters ground range (APRD, Nov. 1982).

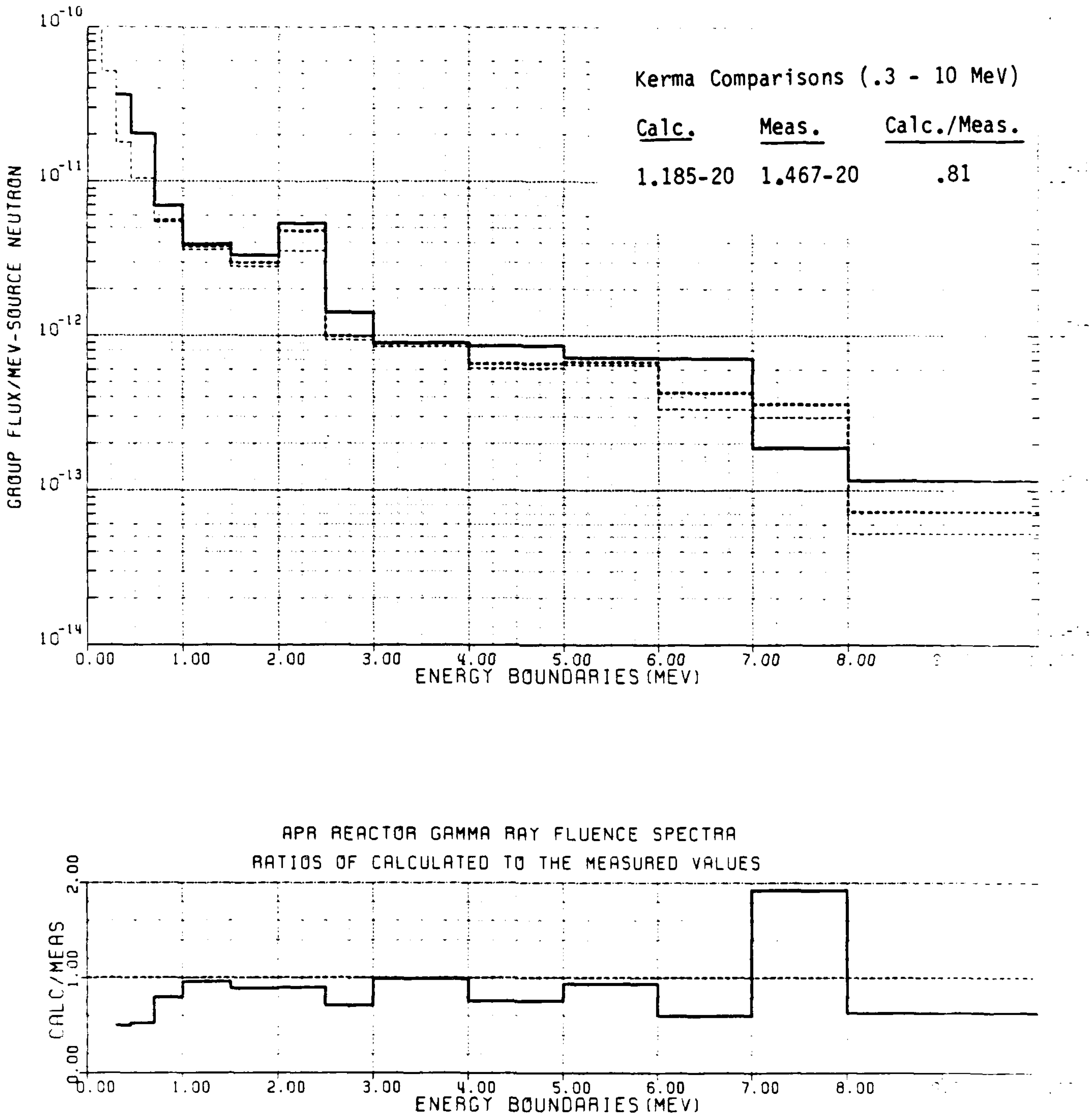


Figure 56. APR reactor gamma ray fluence spectra at 22 meter detector height, calculated and measured at 400 meters ground range (APRD, Nov. 1982).

SECTION 5

REFERENCES

1. J. S. Cheka, et al., "Distribution of Weapons Radiation in Japanese Residential Structures," CEX-62.11, U. S. Atomic Energy Commission (1965).

2. J. A. Auxier, et al., "Technical Concept-Operation BREN," CEX-62.01, U. S. Atomic Energy Commission (1962).

3. J. A. Auxier, "ICHIBAN - Radiation Dosimetry for the Survivors of the Bombings of Hiroshima and Nagasaki," TID-27080, Energy Research Development Agency (1977).

4. M. L. Gritzner, "A User's Manual for the Two-Dimensional Discrete Ordinate Code DOTSAI," SAI-75-747-HU, Science Applications, Inc. (1975).

5. W. A. Rhoades and F. R. Mynatt, "The DOT III Two-Dimensional Discrete Ordinates Transport Code," ORNL-TM-4280, Oak Ridge National Laboratory (1973).

6. W. A. Rhoades, et al., "The DOT-IV Two Dimensional DiscreteOrdinates Transport Code with Space-Dependent Mesh and Quadrature," ORNL/TM-6529, Oak Ridge National Laboratory (1978).

7. R. W. Roussin, "PVC-36 Group, P_5, Photon Interaction Cross Sections for 38 Materials in ANISN Format," DLC-48, Oak Ridge National Laboratory (1977).

8. J. A. Auxier, et al., "General Correlative Studies--Operation BREN," CEX-62.03, U. S. Atomic Energy Commission (1963).

9. J. Pace, Oak Ridge National Laboratory, Private Communication, October 1981.

10. F. F. Haywood, et al., "An Experimental Investigation of the Spatial Distribution of Dose in an Air-Over-Ground Geometry," CEX-62.14, U. S. Atomic Energy Commission (1964).

11. J. H. Hubbell, "Photon Mass Energy-Absorption Coefficient AIR/Medium Ratios for Ionometric Dosimetry 0.1 KeV to 20 MeV," Symposium on Measurements for the Safe Use of Radiation, National Bureau of Standards (1976).

12. N. Sasamoto and K. Tukeuchi, "Analysis of ^{60}Co Gamma-Ray Transport Through Air by Discrete-Ordinates Transport Codes," Nuclear Technology, 47, 189 (1980).

13. W. A. Rhoades, "Development of a Code System for Determining Radiation Protection of Armored Vehicles (The VCS Code)," ORNL-TM-4664, Oak Ridge National Laboratory (1974).

14. R. Little Memo to P. Whalen Subject: "Calculation of APRD Reactor," Los Alamos National Laboratory, 21 January 1982.

15. D. R. Johnson and J. W. Poston, "Radiation Dosimetry Studies at the Health Physics Research Reactor," ORNL-4113, Oak Ridge National Laboratory (1967).

16. A. H. Kazi, et al., Memo for Record, Subject: "Measurement of APRD Reactor $\geq$ 3 MeV Neutron Fluence Source Distribution STEAP-MT-R (8-82), Army Pulse Radiation Division (1982).

17. D. E. Bartine, et al., "Production and Testing of the DNA Few-Group Coupled Neutron-Gamma Cross-Section Library," ORNL/TM-4840, Oak Ridge National Laboratory (1977).

18. F. M. Tomnovec and J. M. Ferguson, "Neutron-Field and Induced-Activity Measurements-Operation BREN," CEX-62.50, U. S. Atomic Energy Commission (1965).

19. R. S. Caswell and J. J. Coyne, "Interaction of Neutrons and Secondary Charge Particles with Tissue: Secondary Particle Spectra," Radiation Research 52, 448-470 (1972).

20. J. H. Thorgate and D. R. Johnson, "The Response of a Neutron Insensitive Gamma Ray Dosimeter as a Function of Photon Energy," Health Physics, Vol. 11, 133, (1965).

21. E.B. Wagner and G.S. Hurst, "A Geiger-Mueller X-Ray Dosimeter with Low Neutron Sensitivity", Health Physics, Vol. 5, 20 (1960).

22. E. A. Straker, "The Effect of the Ground on the Steady-State and Time-Dependent Transport of Neutrons and Secondary Gamma Rays in the Atmosphere," Nuclear Science and Engineering: 46, 334-355 (1971).

23. F. R. Mynatt, Private Communication, Oak Ridge National Laboratory (1981).

24. A. H. Kazi, et al., "Measurements of the Free Field Radiation Environment at the APRD Reactor," APG-MT-5279, Army Pulse Radiation Division (1979).

25. A. H. Kazi, et al., "Neutron and Gamma Radiation Measurements and Calculations up to 1.1 Kilometers from a Fission Source," APG-MT-5490, Army Pulse Radiation Division (1981).

26. H. A. Robitaille and B. E. Hufforth, "A Comparison of Measured and Calculated Air-Transported Radiation from a Fast, Unshielded Nuclear Reactor," DREO, R 835, Defense Research Establishment Ottowa (1980).

27. H. A. Robitaille, letter to Distribution, Subject: "APG-DREO 3611A-2 (PSD), Defense Research Establishment Ottawa (1981).

28. H. A. Robitaille, letter to Distribution, Subject: 1982 Free-Field Measurements at APRF," DREO 10055-2(PSD), Defense Research Establishment Ottawa (1982).

29. W. H. Scott, et al., "NE-213 Detector Perturbations to Measured and Calculated Neutron and Gamma-Ray Fluences in Liquid Air," SAI-78-648-LJ, Science Applications, Inc. (1978).

30. H. A. Robitaille, letter to D. Rigott, Subject; "Re-Analysis of APRD Free-Field Neutron Spectra", DORE 10055-2 (PSD), Defense Research Establishment Ottawa, 5 March 1984.

31. H. A. Robitaille, letter to D. C. Kaul, Subject: "Integral BF_3 Measurements Recorded by DREO at APRD", DREO 10055-2 (PSD), Defense Research Establishment Ottawa, 19 march 1984).

32. C. R. Heimbach, Memo for Record, Subject: "Investigation of Spectra as a function of Height at 400 m," STEAP-MT-R (21-82) Army Pulse Radiation Division (1982).

33. C. R. Heimbach, "Bonner Sphere Measurements of the APRD Free-Field Neutron Environment," APG-MT-5682, Army Pulse Radiation Division (1982).

APPENDIX

TABULATIONS OF CALCULATED KERMA FOR BREN AND APR AND CALCULATED SCALAR FLUENCES FOR APR

Table 10. Calculated BREN Co-60 gamma exposure rate as a function of ground range and detector height (Roentgens/hr).

GROUND RANGE (KM)	DETECTOR HEIGHT 0.15M	1.5M	5.0M	15M	30M
0.2	2.413-20	2.440-20	2.510-20	2.713-20	3.039-20
0.4	8.580-21	8.658-21	8.859-21	9.360-21	1.003-21
0.6	2.421-22	2.441-21	2.494-21	2.625-21	2.784-21
0.8	6.545-22	6.596-22	6.726-22	7.060-22	7.496-22
1.0	1.758-22	1.772-22	1.809-22	1.907-22	2.042-22
1.2	4.962-23	5.005-23	5.114-23	5.410-23	5.823-23
1.4	1.457-23	1.470-23	1.503-23	1.592-23	1.715-23
1.5	7.792-24	7.868-24	8.056-24	8.554-24	9.244-24

Table 11. Calculated BREN reactor neutron kerma rate as a function of ground range and detector height (rads/kw-hr).

GROUND RANGE (KM)	DETECTOR HEIGHT 0.15M	.90M	1.8M	5.6M	14M	33M
0.2	1.549-2	1.604-2	1.617-2	1.666-2	1.777-2	2.045-2
0.4	5.578-3	5.611-3	5.650-3	5.807-3	6.140-3	6.850-3
0.6	1.585-3	1.594-3	1.605-3	1.649-3	1.741-3	1.928-3
0.8	4.481-4	4.506-4	4.537-4	4.661-4	4.918-4	5.437-4
1.0	1.302-4	1.309-4	1.317-4	1.353-4	1.426-4	1.575-4
1.2	3.876-5	3.897-5	3.922-5	4.026-5	4.243-5	4.680-5
1.4	1.180-5	1.186-5	1.194-5	1.225-5	1.290-5	1.422-5
1.6	3.664-6	3.684-6	3.707-6	3.803-6	4.003-6	4.411-6
1.8	1.140-6	1.146-6	1.153-6	1.182-6	1.244-6	1.369-6
2.0	2.647-7	2.632-7	2.629-7	2.656-7	2.762-7	3.016-7

NOTE: COMPUTATION GEOMETRY ENDED AT 2000 METERS HORIZONTAL RANGE ; NO ALBEDOS WERE EMPLOYED. THUS, THE 2000 METER VALUES UNDERESTIMATE THE TRUE KERMA RATES.

Table 12. Calculated BREN reactor gamma exposure rate as a function of ground range and detector height (roentgens/kw-hr).

GROUND RANGE (KM)	DETECTOR HEIGHT 0.15M	.90M	1.8M	5.6M	14M	33M
0.2	3.978-3	3.969-3	3.957-3	3.906-3	3.816-3	3.704-3
0.4	1.604-3	1.601-3	1.597-3	1.582-3	1.554-3	1.509-3
0.6	5.487-4	5.479-4	5.470-4	5.446-4	5.408-4	5.326-4
0.8	1.870-4	1.869-4	1.867-4	1.865-4	1.872-4	1.877-4
1.0	6.650-5	6.648-5	6.646-5	6.656-5	6.727-5	6.867-5
1.2	2.501-5	2.502-5	2.503-5	2.512-5	2.549-5	2.642-5
1.4	9.996-6	1.000-5	1.001-5	1.006-5	1.024-5	1.073-5
1.6	4.238-6	4.242-6	4.248-6	4.277-6	4.356-6	4.594-6
1.8	1.881-6	1.884-6	1.887-6	1.902-6	1.939-6	2.050-6
2.0	8.085-7	8.086-7	8.096-7	8.157-7	8.326-7	8.835-7

NOTE: COMPUTATION GEOMETRY ENDED AT 2000 METERS HORIZONTAL RANGE ; NO ALBEDOS WERE EMPLOYED. THUS, THE 2000 METER VALUES UNDERESTIMATE THE TRUE KERMA RATES.

Table 13. Calculated APR reactor neutron and gamma kerma corresponding to measured values in various periods

		Rad (Tissue)/Source Neutron				
		100m	170m	300m	400m	1075m
WWD	N:	2.448-18	6.466-19	1.101-19	3.718-20	1.158-22*
(March 1978)	G:	4.511-19	1.411-19	3.038-20	1.186-20	1.058-22
APRD	N:	2.620-18	7.359-19	1.324-19	4.553-20	1.521-22
(May/June 1978)	G:	4.189-19	1.348-19	3.032-20	1.208-20	1.159-22
DREO	N:	2.718-18	7.666-19	1.377-19	4.718-20	1.525-22
(Oct/Nov 1980/1981)	G:	4.101-19	1.321-19	2.967-20	1.178-20	1.149-22

*Computations were performed at 1075m. The measurements were performed to a nominal range of 1080 ± 5m (reference 26) although distances quoted to the same point have included 1100m (reference 23, 24) and 1070m (reference 25).

Table 14. Calculated APR reactor neutron fluence spectra corresponding to WWD measurements March 1978.

GROUP FLUENCE/MEV-SOURCE NEUTRON

UPPER E (MEV)	GROUND RANGE 100M	170M	300M
1.96+1	7.635-17	1.663-17	2.401-18
1.69+1	3.369-15	7.179-16	9.819-17
1.49+1	1.592-14	3.325-15	4.338-16
1.42+1	1.291-14	2.805-15	3.961-16
1.38+1	2.996-14	6.400-15	8.710-16
1.28+1	5.195-14	1.114-14	1.521-15
1.22+1	1.074-13	2.361-14	3.357-15
1.11+1	2.629-13	5.934-14	8.792-15
1.00+1	6.239-13	1.459-13	2.292-14
9.05+0	1.319-12	3.126-13	5.023-14
8.19+0	2.332-12	5.374-13	8.221-14
7.41+0	4.584-12	1.118-12	1.874-13
6.38+0	1.137-11	2.778-12	4.702-13
4.97+0	2.135-11	5.624-12	1.069-12
4.72+0	2.477-11	5.649-12	8.604-13
4.07+0	4.371-11	9.569-12	1.309-12
3.01+0	9.690-11	2.418-11	3.966-12
2.39+0	1.351-10	3.622-11	6.629-12
2.31+0	1.424-10	3.648-11	6.181-12
1.83+0	2.369-10	6.033-11	9.911-12
1.11+0	4.893-10	1.344-10	2.377-11
5.50-1	8.357-10	2.360-10	4.092-11
1.58-1	1.541-09	4.672-10	8.357-11
1.11-1	1.790-09	5.962-10	1.144-10
5.25-2	2.808-09	9.882-10	1.986-10
2.48-2	4.063-09	1.451-09	2.946-10
2.19-2	5.378-09	1.975-09	4.137-10
1.03-2	1.166-08	4.419-09	9.637-10
3.35-3	3.102-08	1.199-08	2.690-09
1.23-3	7.184-08	2.802-08	6.393-09
5.83-4	2.101-07	8.296-08	1.941-08
1.01-4	9.413-07	3.756-07	8.947-08
2.90-5	2.839-06	1.143-06	2.761-07
1.07-5	8.067-06	3.269-06	7.993-07
3.06-6	2.392-05	9.723-06	2.393-06
1.13-6	5.977-05	2.425-05	5.973-06
4.14-7	1.192-03	4.447-04	9.988-05

Table 15. Calculated APR reactor gamma ray fluence spectra corresponding to WWD measurements March 1978.

UPPER E (MEV)	GROUP FLUENCE/MEV-SOURCE NEUTRON			GROUP FLUENCE/MEV-SOURCE NEUTRON INCLUDING NE213 SECONDARY GAMMAS		
	GROUND RANGE			GROUND RANGE		
	100M	170M	300M	100M	170M	300M
14.0	2.409-13	1.093-13	3.480-14	2.411-13	1.094-13	3.481-14
10.0	1.112-12	3.739-13	9.418-14	1.864-12	6.557-13	1.578-13
8.0	7.632-12	2.718-12	6.257-13	9.987-12	3.602-12	8.258-13
7.0	8.218-12	2.970-12	7.063-13	1.147-11	4.190-12	9.827-13
6.0	1.368-11	5.240-12	1.356-12	1.474-11	5.637-12	1.446-12
5.0	1.727-11	5.861-12	1.338-12	1.890-11	6.424-12	1.460-12
4 0	2.513-11	8.154-12	1.822-12	2.635-11	8.582-12	1.916-12
3.0	3.540-11	1.023-11	2.113-12	3.759-11	1.101-11	2.284-12
2.5	1.808-10	6.082-11	1.303-11	2.106-10	7.206-11	1.560-11
2.0	1.242-10	3.504-11	6.819-12	1.300-10	3.705-11	7.329-12
1.5	1.845-10	4.749-11	8.642-12	1.903-10	4.929-11	9.007-12
1.0	2.840-10	7.140-11	1.292-11	2.885-10	7.274-11	1.318-11
0.7	4.452-10	1.214-10	2.432-11	4.452-10	1.214-10	2.432-11
0.45	6.619-10	1.993-10	4.232-11	6.619-10	1.993-10	4.232-11
0.30	1.678-09	5.615-10	1.233-10	1.678-09	5.615-10	1.233-10
0.15	3.253-09	1.190-09	2.717-10	3.253-09	1.190-09	2.717-10
0.10	4.721-09	1.902-09	4.618-10	4.721-09	1.902-09	4.618-10
0.07	4.358-09	2.006-09	5.424-10	4.358-09	2.006-09	5.424-10
0.045	1.657-09	8.350-10	2.411-10	1.657-09	8.350-10	2.411-10
0.03	1.770-10	9.137-11	2.670-11	1.770-10	9.137-11	2.670-11
0.02	1.715-12	8.767-13	2.549-13	1.715-12	8.767-13	2.549-13

Table 16. Calculated APR reactor neutron fluence spectra corresponding to APRD measurements May/June 1978.

GROUP FLUENCE/MEV-SOURCE NEUTRON

UPPER E (MEV)	GROUND RANGE 100M	170M	300M
1.96+1	7.504-17	1.748-17	2.739-18
1.69+1	3.312-15	7.514-16	1.115-16
1.49+1	1.567-14	3.466-15	4.890-16
1.42+1	1.271-14	2.954-15	4.543-16
1.38+1	2.956-14	6.689-15	9.830-16
1.28+1	5.130-14	1.164-14	1.714-15
1.22+1	1.063-13	2.466-14	3.774-15
1.11+1	2.610-13	6.189-14	9.830-15
1.00+1	6.217-13	1.521-13	2.552-14
9.05+0	1.315-12	3.258-13	5.584-14
8.19+0	2.323-12	5.616-13	9.174-14
7.41+0	4.593-12	1.174-12	2.097-13
6.38+0	1.147-11	2.955-12	5.324-13
4.97+0	2.162-11	5.997-12	1.216-12
4.72+0	2.505-11	6.069-12	9.818-13
4.07+0	4.439-11	1.029-11	1.488-12
3.01+0	1.000-10	2.626-11	4.571-12
2.39+0	1.410-10	3.966-11	7.673-12
2.31+0	1.466-10	3.958-11	7.046-12
1.83+0	2.478-10	6.674-11	1.144-11
1.11+0	5.293-10	1.539-10	2.853-11
5.50-1	9.456-10	2.821-10	5.161-11
1.58-1	1.775-09	5.631-10	1.063-10
1.11-1	2.075-09	7.232-10	1.478-10
5.25-2	3.266-09	1.208-09	2.602-10
2.48-2	4.722-09	1.766-09	3.842-10
2.19-2	6.226-09	2.396-09	5.383-10
1.03-2	1.345-08	5.322-09	1.245-09
3.35-3	3.560-08	1.434-08	3.450-09
1.23-3	8.231-08	3.351-08	8.188-09
5.83-4	2.388-07	9.852-08	2.469-08
1.01-4	1.065-06	4.433-07	1.130-07
2.90-5	3.204-06	1.345-06	3.471-07
1.07-5	9.068-06	3.830-06	9.998-07
3.06-6	2.681-05	1.135-05	2.980-06
1.13-6	6.676-05	2.821-05	7.405-06
4.14-7	1.227-03	4.781-04	1.148-04

Table 17. Calculated APR reactor gamma ray fluence spectra corresponding to APRD measurements May/June 1978.

UPPER E (MEV)	GROUP FLUENCE/MEV-SOURCE NEUTRON GROUND RANGE 100M	 170M	 300M	GROUP FLUENCE/MEV-SOURCE NEUTRON INCLUDING NE213 SECONDARY GAMMAS GROUND RANGE 100M	 170M	 300M
14.0	2.541-13	1.200-13	4.054-14	2.543-13	1.201-13	4.056-14
10.0	1.254-12	4.376-13	1.134-13	2.036-12	7.435-13	1.873-13
8.0	8.132-12	3.030-12	7.404-13	1.059-11	3.993-12	9.736-13
7.0	8.177-12	3.090-12	7.842-13	1.157-11	4.421-12	1.107-12
6.0	1.115-11	4.528-12	1.293-12	1.226-11	4.961-12	1.397-12
5.0	1.786-11	6.328-12	1.527-12	1.956-11	6.941-12	1.669-12
4.0	2.616-11	8.856-12	2.090-12	2.742-11	9.323-12	2.200-12
3.0	3.495-11	1.039-11	2.249-12	3.722-11	1.124-11	2.448-12
2.5	1.341-10	4.581-11	1.034-11	1.665-10	5.858-11	1.346-11
2.0	1.180-10	3.403-11	6.983-12	1.241-10	3.623-11	7.494-12
1.5	1.773-10	4.735-11	9.027-12	1.833-10	4.933-11	9.453-12
1.0	2.700-10	7.088-11	1.332-11	2.747-10	7.235-11	1.363-11
0.7	4.247-10	1.210-10	2.483-11	4.247-10	1.210-10	2.483-11
0.45	6.294-10	1.950-10	4.179-11	6.294-10	1.950-10	4.179-11
0.30	1.609-09	5.460-10	1.203-10	1.609-09	5.460-10	1.203-10
0.15	3.164-09	1.158-09	2.642-10	3.164-09	1.158-09	2.642-10
0.10	4.612-09	1.847-09	4.460-10	4.612-09	1.847-09	4.460-10
0.07	4.221-09	1.923-09	5.148-10	4.221-09	1.923-09	5.148-10
0.045	1.584-09	7.882-10	2.250-10	1.584-09	7.882-10	2.250-10
0.03	1.647-10	8.381-11	2.420-11	1.647-10	8.381-11	2.420-11
0.02	1.554-12	7.729-13	2.205-13	1.554-12	7.729-13	2.205-13

Table 18. Calculated APR reactor neutron fluence spectra corresponding to DREO measurements Oct. 1980.

GROUP FLUENCE/MEV-SOURCE NEUTRON

UPPER E (MEV)	GROUND RANGE 100M	170M	300M	400M	1075M
1.96+1	7.543-17	1.758-17	2.758-18	8.850-19	3.110-21
1.69+1	3.329-15	7.555-16	1.123-16	3.444-17	8.656-20
1.49+1	1.574-14	3.484-15	4.923-16	1.454-16	2.823-19
1.42+1	1.278-14	2.970-15	4.573-16	1.431-16	3.529-19
1.38+1	2.971-14	6.725-15	9.896-16	3.013-16	6.801-19
1.28+1	5.157-14	1.170-14	1.725-15	5.259-16	1.174-18
1.22+1	1.068-13	2.477-14	3.793-15	1.189-15	3.062-18
1.11+1	2.623-13	6.217-14	9.878-15	3.181-15	9.635-18
1.00+1	6.248-13	1.527-13	2.562-14	8.589-15	3.329-17
9.05+0	1.321-12	3.270-13	5.599-14	1.907-14	8.070-17
8.19+0	2.336-12	5.643-13	9.214-14	3.032-14	1.054-16
7.41+0	4.622-12	1.180-12	2.104-13	7.357-14	3.439-16
6.38+0	1.158-11	2.979-12	5.364-13	1.892-13	9.207-16
4.97+0	2.182-11	6.039-12	1.221-12	4.650-13	3.383-15
4.72+0	2.540-11	6.150-12	9.961-13	3.310-13	1.431-15
4.07+0	4.506-11	1.045-11	1.514-12	4.596-13	1.175-15
3.01+0	1.022-10	2.679-11	4.657-12	1.575-12	5.214-15
2.39+0	1.449-10	4.067-11	7.845-12	2.832-12	1.205-14
2.31+0	1.492-10	4.032-11	7.171-12	2.455-12	8.036-15
1.83+0	2.546-10	6.875-11	1.179-11	3.941-12	1.145-14
1.11+0	5.504-10	1.606-10	2.972-11	1.030-11	3.149-14
5.50-1	1.006-09	3.024-10	5.518-11	1.905-11	5.944-14
1.58-1	1.906-09	6.070-10	1.138-10	3.950-11	1.240-13
1.11-1	2.262-09	7.845-10	1.574-10	5.561-11	1.776-13
5.25-2	3.597-09	1.316-09	2.764-10	9.904-11	3.210-13
2.48-2	5.202-09	1.926-09	4.082-10	1.467-10	4.773-13
2.19-2	6.889-09	2.629-09	5.748-10	2.088-10	6.875-13
1.03-2	1.490-08	5.878-09	1.338-09	4.946-10	1.664-12
3.35-3	3.957-08	1.597-08	3.747-09	1.404-09	4.807-12
1.23-3	9.106-08	3.717-08	8.879-09	3.357-09	1.165-11
5.83-4	2.636-07	1.095-07	2.694-08	1.037-08	3.708-11
1.01-4	1.173-06	4.934-07	1.239-07	4.825-08	1.765-10
2.90-5	3.519-06	1.496-06	3.814-07	1.500-07	5.593-10
1.07-5	9.940-06	4.263-06	1.103-06	4.383-07	1.670-09
3.06-6	2.932-05	1.263-05	3.295-06	1.318-06	5.102-09
1.13-6	7.287-05	3.137-05	8.206-06	3.294-06	1.290-08
4.14-7	1.187-03	4.711-04	1.132-04	4.401-05	1.652-07

Table 19. Calculated APR reactor gamma ray fluence spectra corresponding to DREO measurements October 1980.

UPPER E	GROUP FLUENCE/MEV-SOURCE NEUTRON					GROUP FLUENCE/MEV-SOURCE NEUTRON INCLUDING NE213 SECONDARY GAMMAS				
	GROUND RANGE									
(MEV)	100M	170M	300M	400M	1075M	100M	170M	300M	400M	1075M
14.0	2.509-13	1.206-13	4.143-14	2.088-14	5.590-16	2.512-13	1.207-13	4.145-14	2.089-14	5.590-16
10.0	1.280-12	4.511-13	1.172-13	5.194-14	1.063-15	2.047-12	7.567-13	1.910-13	8.065-14	1.171-15
8.0	8.596-12	3.247-12	7.911-13	3.190-13	2.992-15	1.102-11	4.215-12	1.025-12	4.102-13	3.334-15
7.0	8.582-12	3.285-12	8.316-13	3.463-13	3.918-15	1.193-11	4.624-12	1.156-12	4.726-13	4.392-15
6.0	1.136-11	4.670-12	1.341-12	6.074-13	9.183-15	1.246-11	5.105-12	1.446-12	6.482-13	9.336-15
5.0	1.864-11	6.697-12	1.615-12	6.368-13	6.977-15	2.033-11	7.315-12	1.758-12	7.117-13	7.187-15
4.0	2.711-11	9.302-12	2.198-12	8.907-13	9.206-15	2.836-11	9.774-12	2.308-12	9.331-13	9.367-15
3.0	3.578-11	1.076-11	2.339-12	9.271-13	1.020-14	3.803-11	1.161-11	2.539-12	1.004-12	1.049-14
2.5	1.117-10	3.770-11	8.428-12	3.240-12	2.028-14	1.456-10	5.122-11	1.171-11	4.512-12	2.500-14
2.0	1.169-10	3.364-11	6.881-12	2.605-12	2.009-14	1.229-10	3.587-11	7.397-12	2.803-12	2.083-14
1.5	1.757-10	4.680-11	8.877-12	3.252-12	2.542-14	1.817-10	4.881-11	9.309-12	3.413-12	2.601-14
1.0	2.680-10	7.017-11	1.312-11	4.806-12	3.755-14	2.727-10	7.168-11	1.343-11	4.920-12	3.796-14
0.7	4.220-10	1.202-10	2.461-11	9.453-12	7.869-14	4.220-10	1.202-10	2.461-11	9.453-12	7.869-14
0.45	6.211-10	1.922-10	4.107-11	1.590-11	1.248-13	6.211-10	1.922-10	4.107-11	1.590-11	1.248-13
0.30	1.583-09	5.372-10	1.183-10	4.582-11	3.496-13	1.583-09	5.372-10	1.183-10	4.582-11	3.496-13
0.15	3.104-09	1.137-09	2.595-10	1.012-10	7.665-13	3.104-09	1.137-09	2.595-10	1.012-10	7.665-13
0.10	4.483-09	1.799-09	4.354-10	1.720-10	1.297-12	4.483-09	1.799-09	4.354-10	1.720-10	1.297-12
0.07	4.008-09	1.845-09	4.981-10	2.025-10	1.544-12	4.008-09	1.845-09	4.981-10	2.025-10	1.544-12
0.045	••	••	••	••	••	••	••	••	••	••
0.03	••	••	••	••	••	••	••	••	••	••
0.02	••	••	••	••	••	••	••	••	••	••

Table 20. Calculated APR reactor neutron fluence spectra vs. height at 400m ground range corresponding to APRD measurements Nov. 1982.

	GROUP FLUENCE/MEV-SOURCE NEUTRON		
UPPER E		HEIGHT	
(MEV)	2M	12M	22M
1.96+1	8.794-19	9.546-19	1.026-18
1.69+1	3.421-17	3.684-17	3.951-17
1.49+1	1.444-16	1.546-16	1.648-16
1.42+1	1.422-16	1.537-16	1.651-16
1.38+1	2.993-16	3.208-16	3.422-16
1.28+1	5.224-16	5.591-16	5.956-16
1.22+1	1.183-15	1.262-15	1.341-15
1.11+1	3.165-15	3.357-15	3.555-15
1.00+1	8.557-15	9.029-15	9.527-15
9.05+0	1.903-14	2.005-14	2.117-14
8.19+0	3.021-14	3.199-14	3.391-14
7.41+0	7.338-14	7.749-14	8.206-14
6.38+0	1.882-13	2.007-13	2.131-13
4.97+0	4.643-13	4.918-13	5.208-13
4.72+0	3.274-13	3.527-13	3.767-13
4.07+0	4.528-13	4.863-13	5.185-13
3.01+0	1.549-12	1.630-12	1.730-12
2.39+0	2.779-12	2.934-12	3.107-12
2.31+0	2.430-12	2.627-12	2.818-12
1.83+0	3.860-12	4.227-12	4.550-12
1.11+0	1.002-11	1.097-11	1.181-11
5.50-1	1.818-11	2.039-11	2.231-11
1.58-1	3.779-11	4.326-11	4.798-11
1.11-1	5.370-11	6.211-11	6.960-11
5.25-2	9.609-11	1.118-10	1.261-10
2.48-2	1.424-10	1.660-10	1.876-10
2.19-2	2.019-10	2.346-10	2.651-10
1.03-2	4.758-10	5.492-10	6.190-10
3.35-3	1.337-09	1.527-09	1.711-09
1.23-3	3.199-09	3.627-09	4.039-09
5.83-4	9.805-09	1.103-08	1.221-08
1.01-4	4.537-08	5.058-08	5.570-08
2.90-5	1.406-07	1.558-07	1.707-07
1.07-5	4.082-07	4.479-07	4.873-07
3.06-6	1.220-06	1.315-06	1.412-06
1.13-6	3.029-06	3.176-06	3.344-06
4.14-7	4.410-05	3.478-05	2.789-05

Table 21. Calculated APR reactor gamma ray fluence spectra vs. height at 400m ground range corresponding to APRD measurements Nov. 1982.

UPPER E (MEV)	GROUP FLUENCE/MEV-SOURCE NEUTRON HEIGHT 2M	12M	22M	GROUP FLUENCE/MEV-SOURCE NEUTRON INCLUDING NE213 SECONDARY GAMMAS HEIGHT 2M	12M	22M
14.0	2.043-14	2.186-14	2.320-14	2.044-14	2.187-14	2.321-14
10.0	5.049-14	5.262-14	5.261-14	7.901-14	7.616-14	7.256-14
8.0	3.010-13	3.112-13	2.953-13	3.913-13	3.869-13	3.608-13
7.0	3.292-13	3.427-13	3.338-13	4.540-13	4.482-13	4.255-13
6.0	5.893-13	6.268-13	6.443-13	6.297-13	6.608-13	6.738-13
5.0	6.250-13	6.337-13	6.130-13	6.793-13	6.813-13	6.560-13
4.0	8.514-13	8.663-13	8.497-13	8.933-13	9.026-13	8.821-13
3.0	8.940-13	9.249-13	9.325-13	9.704-13	9.902-13	9.900-13
2.5	3.968-12	3.768-12	3.546-12	5.191-12	4.977-12	4.763-12
2.0	2.656-12	2.760-12	2.800-12	2.852-12	2.931-12	2.954-12
1.5	3.328-12	3.498-12	3.628-12	3.487-12	3.644-12	3.767-12
1.0	4.919-12	5.212-12	5.453-12	5.032-12	5.319-12	5.557-12
0.7	9.607-12	1.010-11	1.050-11	9.607-12	1.010-11	1.050-11
0.45	1.631-11	1.717-11	1.784-11	1.631-11	1.717-11	1.784-11
0.30	4.694-11	4.929-11	5.119-11	4.694-11	4.929-11	5.119-11
0.15	1.038-10	1.100-10	1.150-10	1.038-10	1.100-10	1.150-10
0.10	1.781-10	1.938-10	2.062-10	1.781-10	1.938-10	2.062-10
0.07	2.141-10	2.523-10	2.826-10	2.141-10	2.523-10	2.826-10
0.045	9.710-11	1.289-10	1.539-10	9.710-11	1.289-10	1.539-10
0.03	1.084-11	1.693-11	2.139-11	1.084-11	1.693-11	2.139-11
0.02	1.052-13	1.884-13	2.396-13	1.052-13	1.884-13	2.396-13

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